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ABSTRACT

As one of three audiovisual media in the U. S. Naval Academy Self-Paced Physics Course, 27 topics relating to mechanics, electricity, and magnetism are presented in this volume for enriching and supplementary purposes. Each topic is primarily composed of illustrations and formulas. Terminal behavior objectives and directions for reaching subsequent study guides are provided at the end of the topic. The material is designed to be used in combination with tape recorded lectures. (Related documents are SE 016 065 through SE 016 088 and ED 062 123 through ED 062 125.) (CC)

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NEW YORK INSTITUTE OF TECHNOLOGY, OLD WESTBURY, LONG ISLAND, NEW YORK 11568

TALKING BOOKS

(MASTER SET)

TALKING BOOKS

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24. FORCE BETWEEN PARALLEL CURRENT-CARRYING CONDUCTORS

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22. MOTION OF AN ELECTRON IN COMBINED E AND B FIELDS

28. L - R TRANSIENTS

27. R - C TRANSIENTS

PROJECTILE MOTION

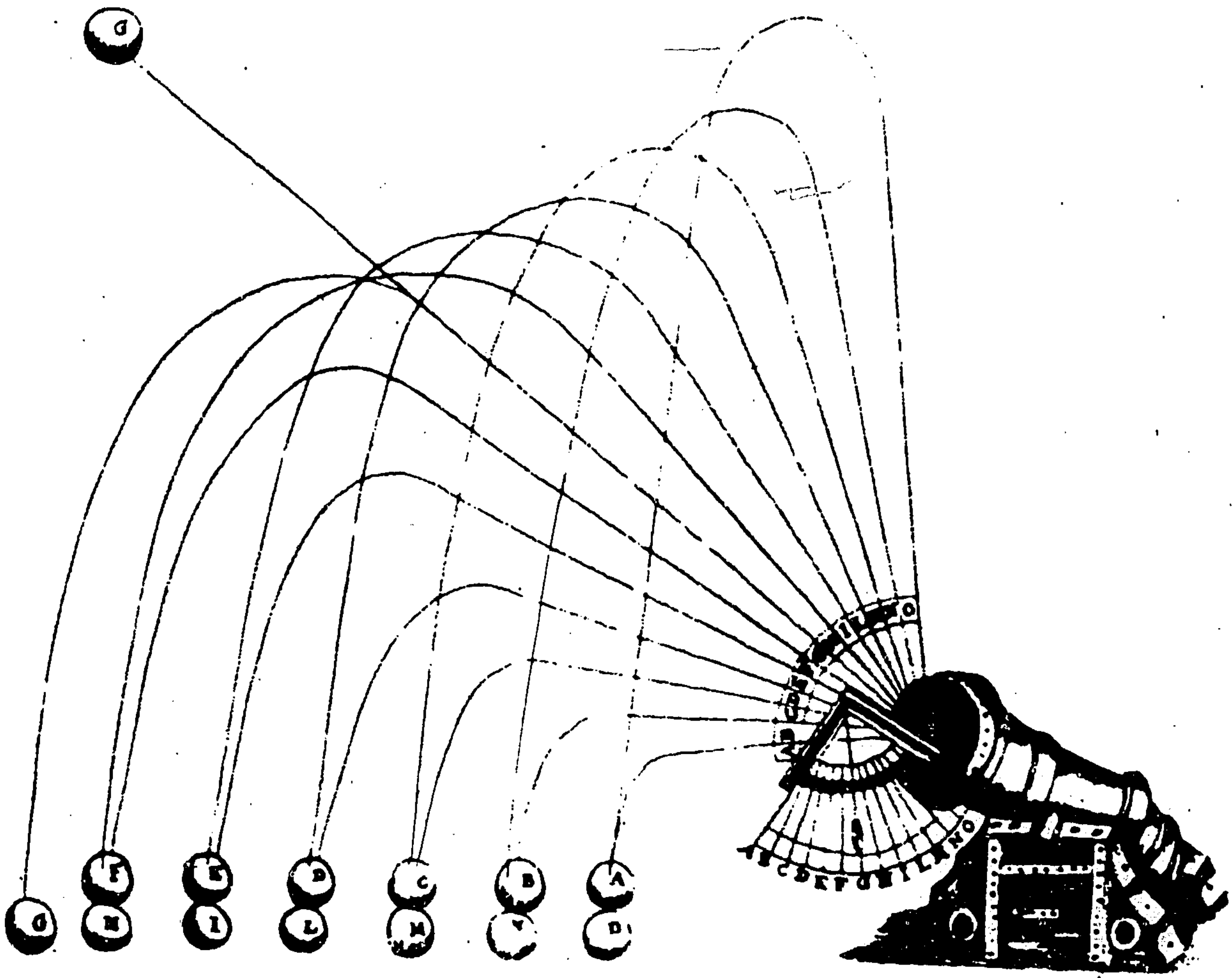


FIGURE 1

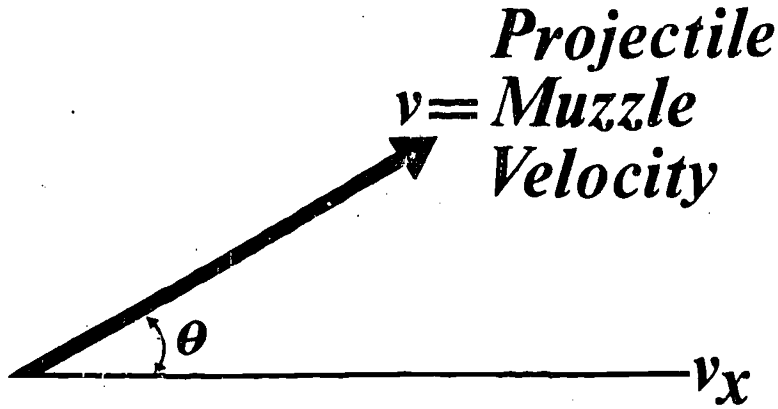


FIGURE (2)

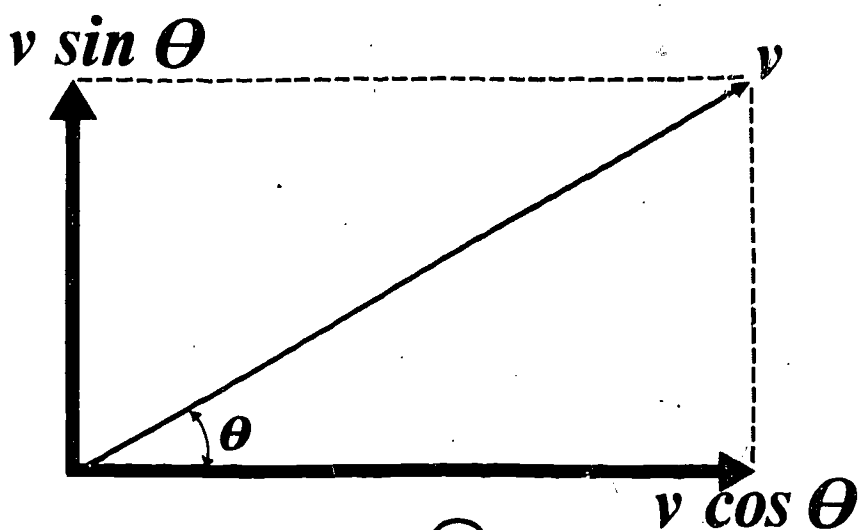


FIGURE (3)

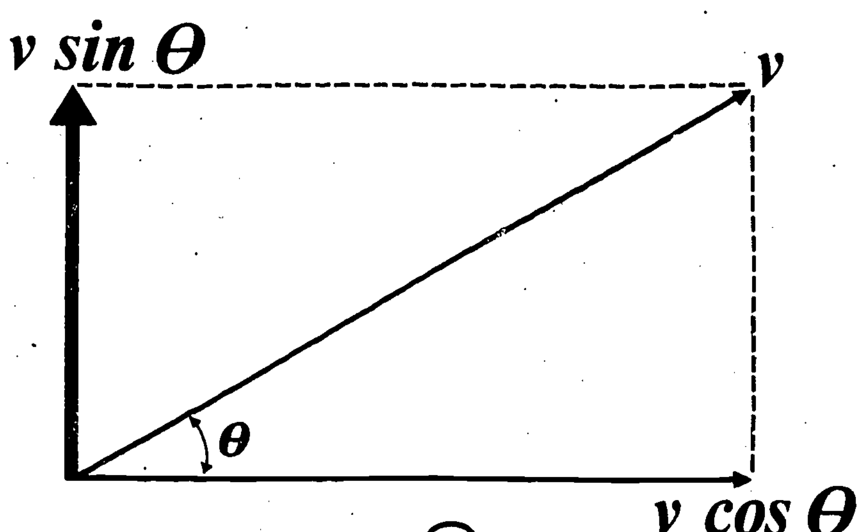


FIGURE (4)

$$v = v_y - gt$$

But At Maximum Height $v = 0$

So $v_y = gt$ **or** $t = \frac{v_y}{g} = \frac{v \sin \Theta}{g}$

FIGURE 5

$$\text{time of flight} = \frac{2v \sin \Theta}{g}$$

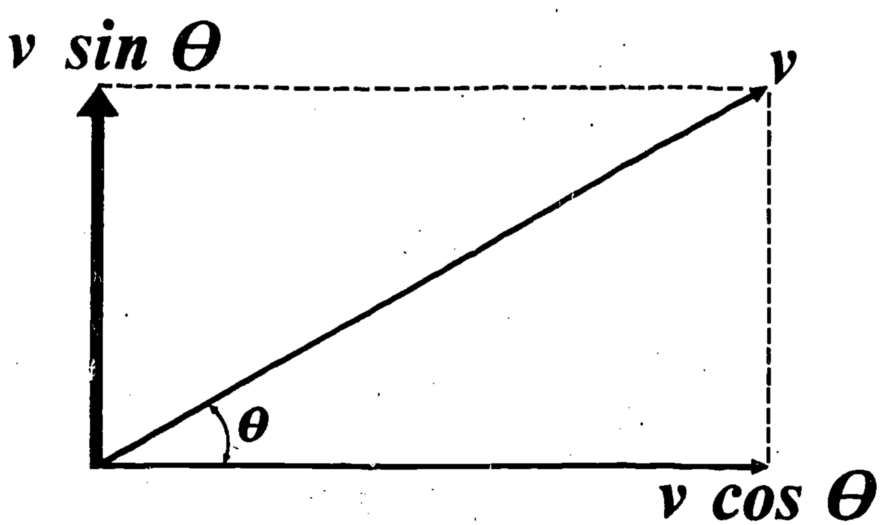


FIGURE 6

$$t_{flight} = \frac{2v \sin \theta}{g}$$

$$Range = \frac{2v^2 \sin \theta}{g} \cdot \cos \theta$$

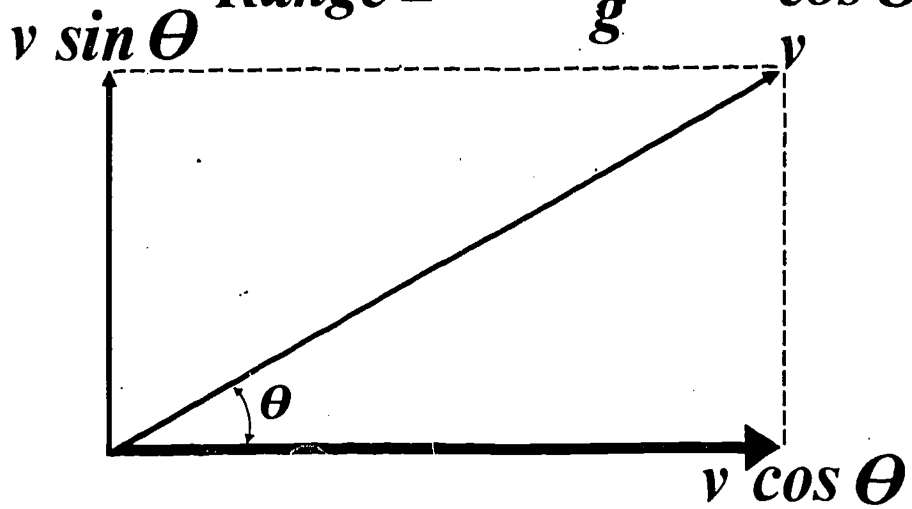


FIGURE 7

$$t_f = \frac{2v \sin \theta}{g}$$

$$R = \frac{2v^2 \sin \theta \cos \theta}{g}$$

$$= \frac{v^2 \sin 2\theta}{g}$$

FIGURE 8

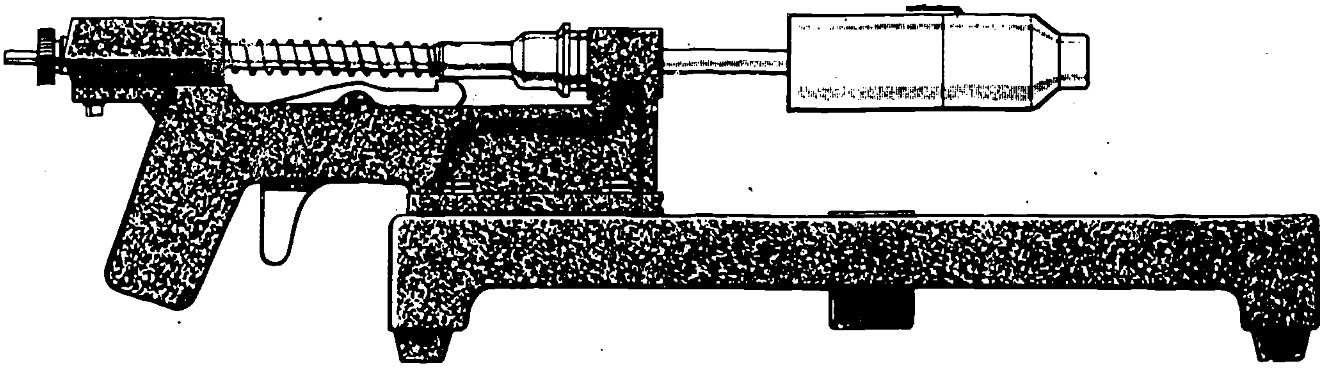


FIGURE 9

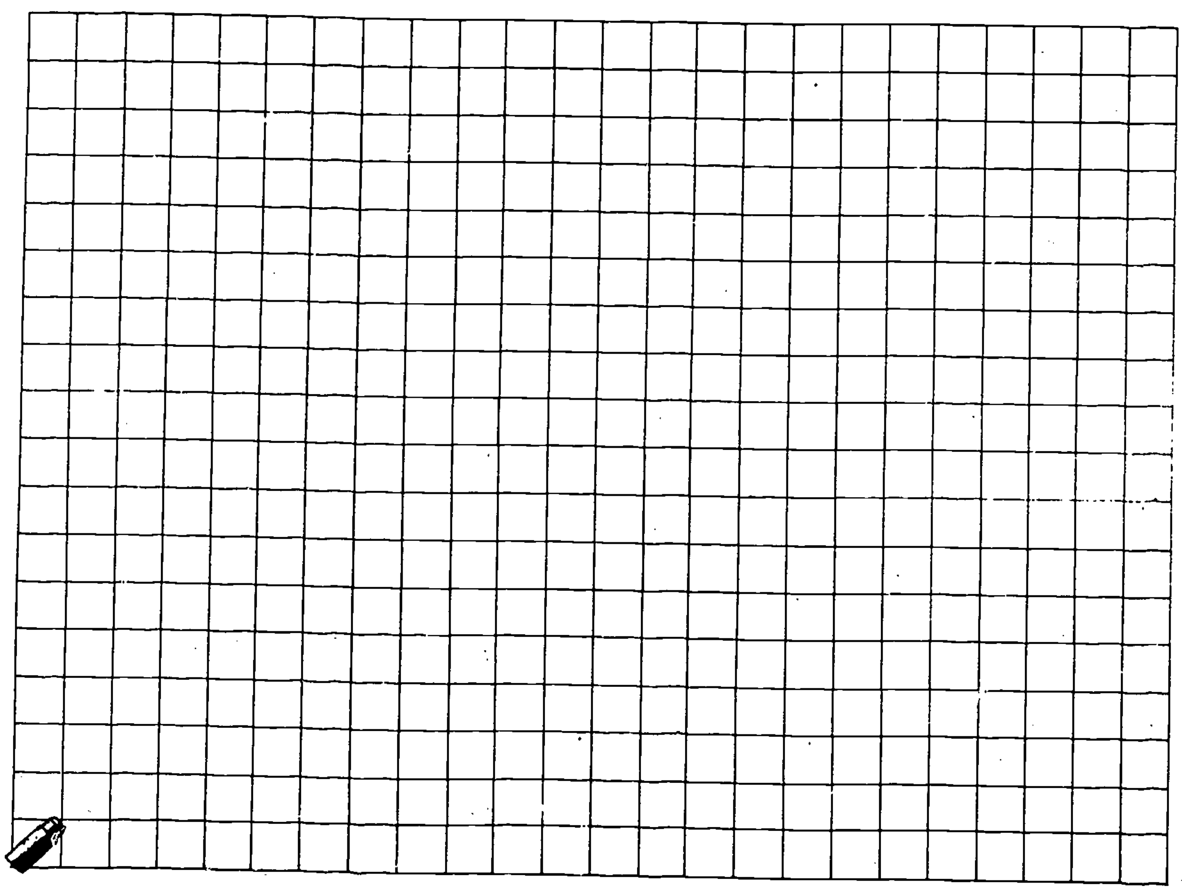


FIGURE 10

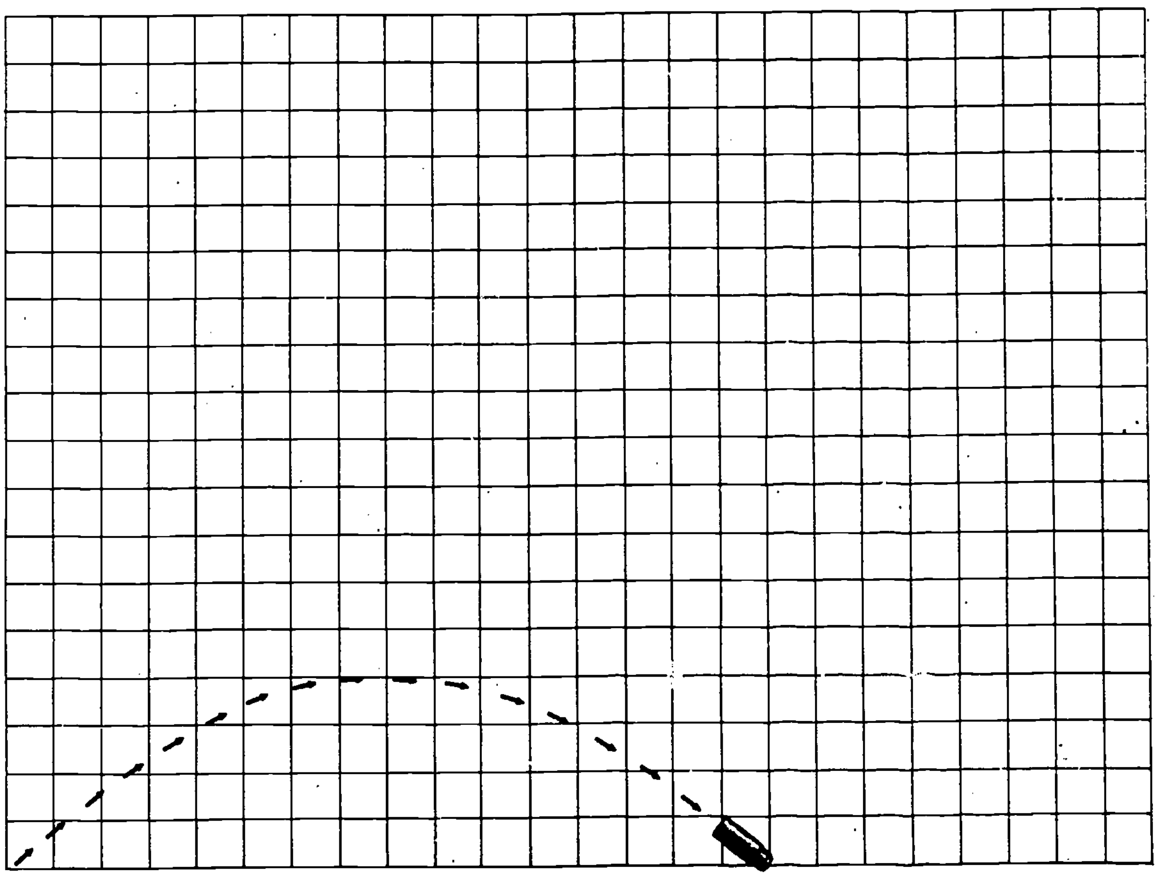


FIGURE 11

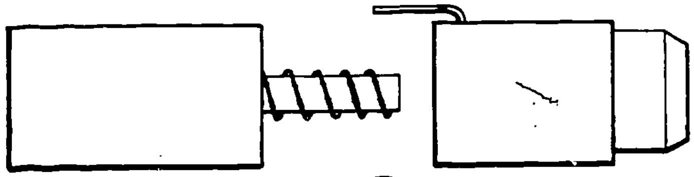


FIGURE 12

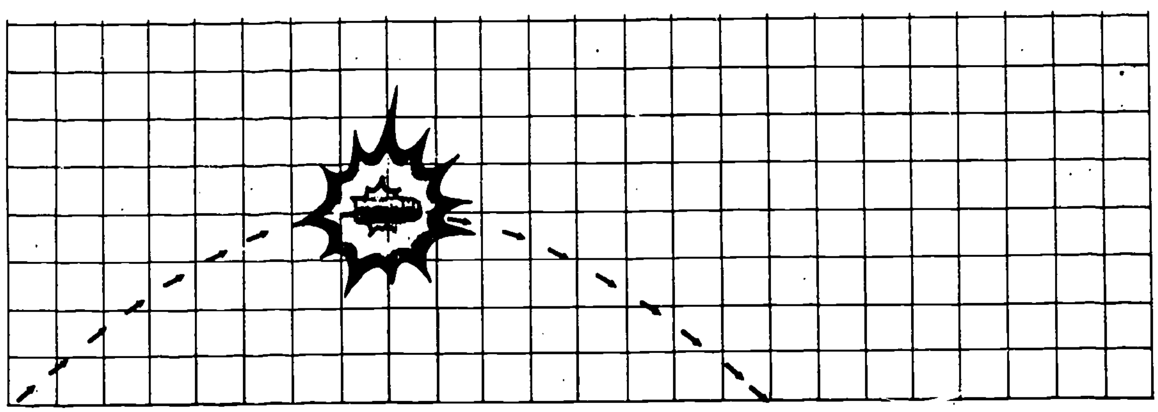


FIGURE 13

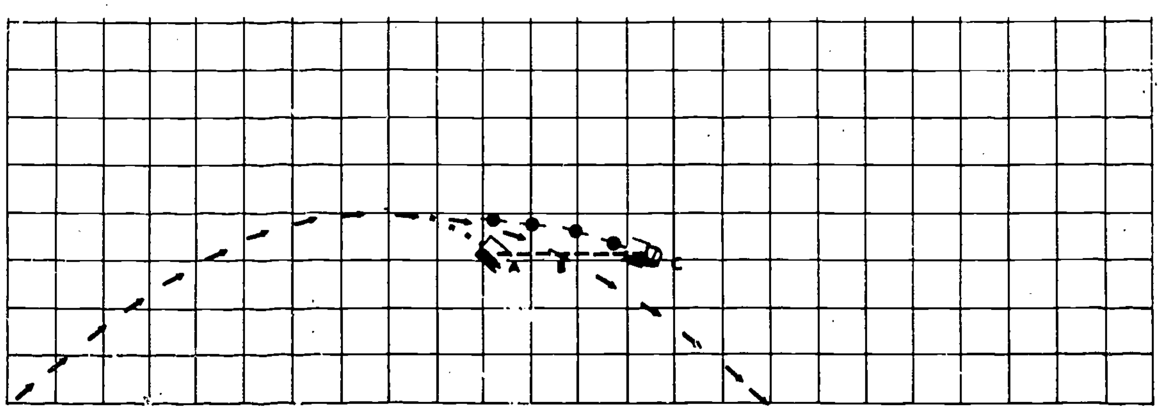


FIGURE 14

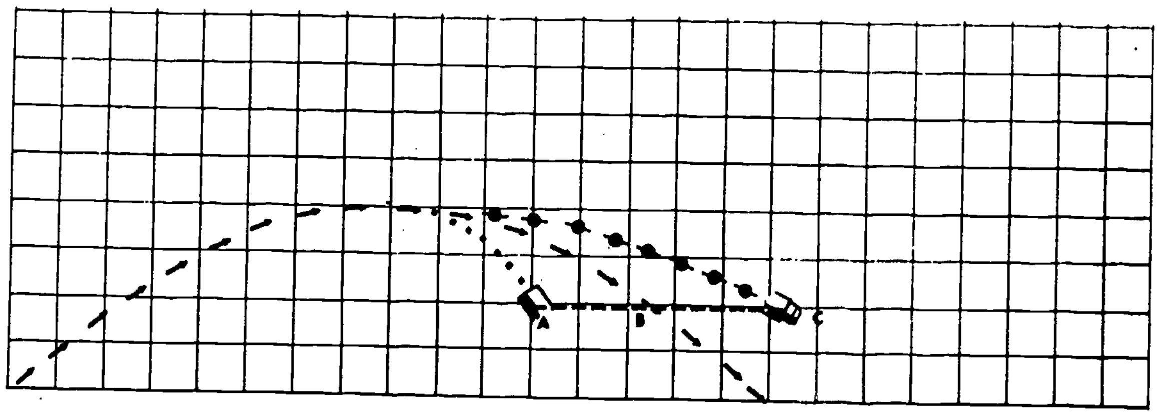


FIGURE 15

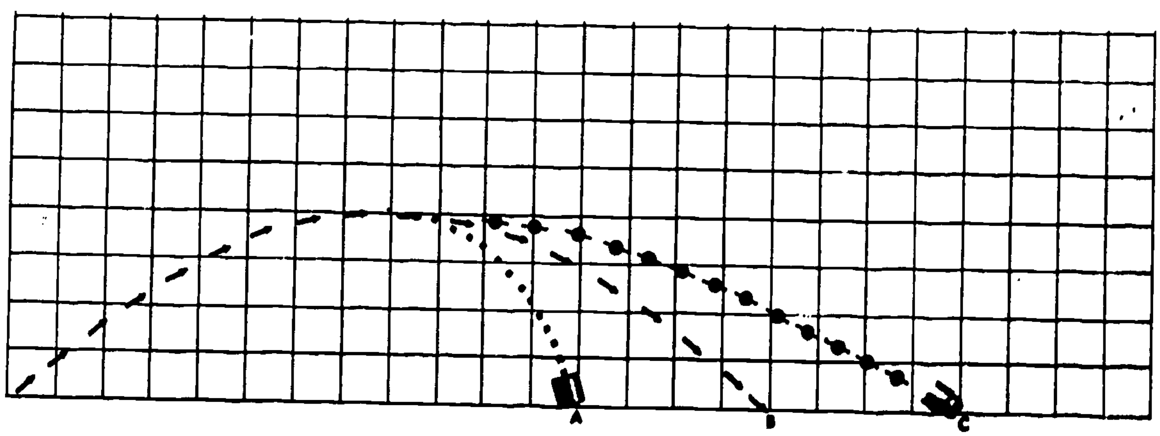


FIGURE 16

PROJECTILE MOTION

TERMINAL OBJECTIVES

2/3 B Analyze the trajectory curve of a particle projected horizontally (no vertical component) from the top of a structure.

2/3 E Solve position, time velocity, and range problems involving projectiles with any angle of departure.

Please turn to page 22A of your STUDY GUIDE to continue with your work.

Newton's 1st Law

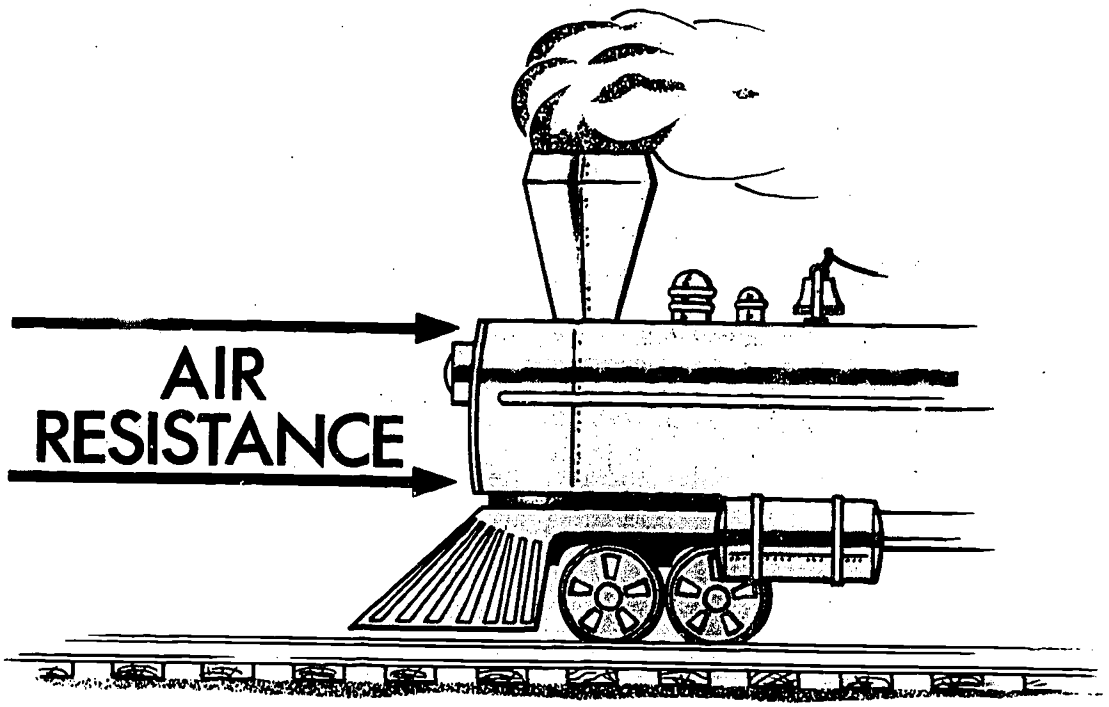


FIGURE 1

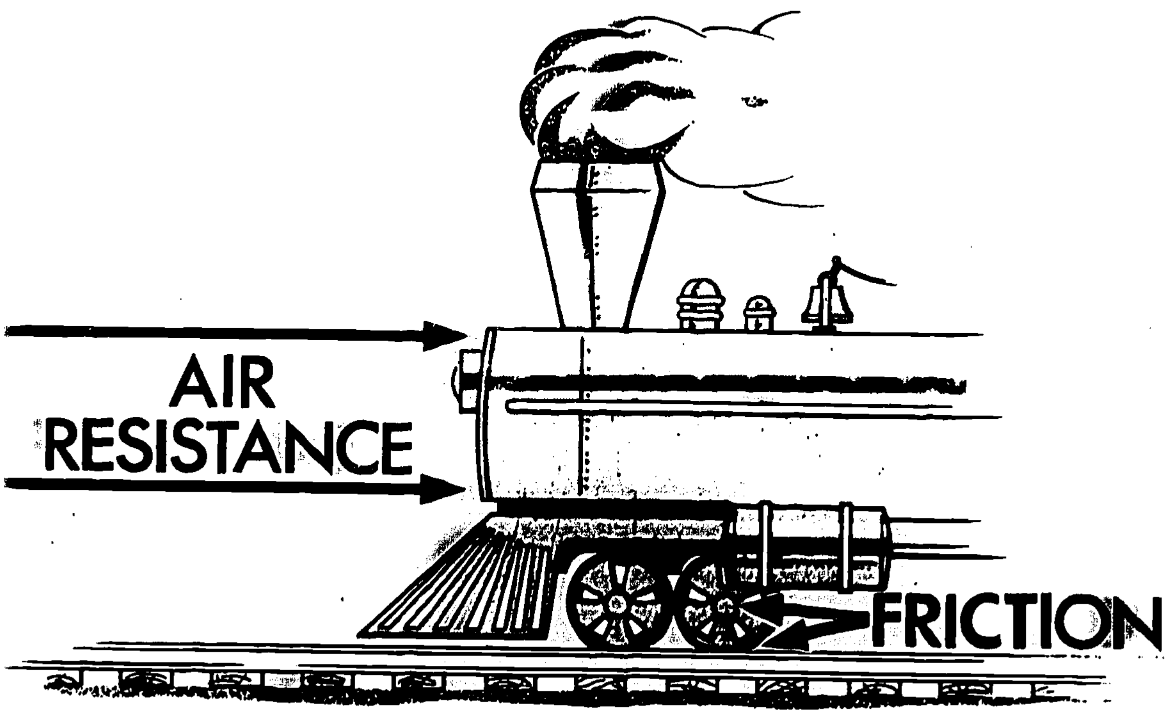


FIGURE 2

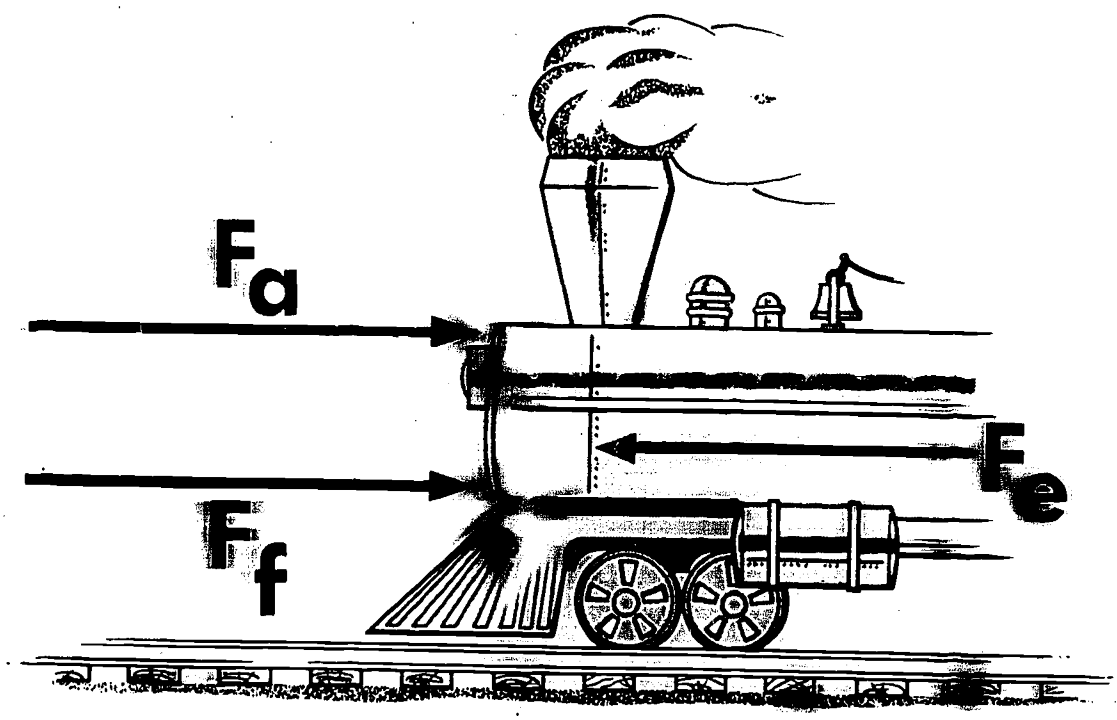


FIGURE (3)

NEWTON'S FIRST LAW
OF MOTION

A BODY REMAINS AT REST OR IN MOTION WITH UNIFORM VELOCITY UNLESS ACTED UPON BY AN EXTERNAL, UNBALANCED FORCE

FIGURE 4

ONCE A BODY HAS BEEN SET IN MOTION IT IS NO LONGER NECESSARY TO EXERT A FORCE ON IT TO KEEP IT MOVING.

FIGURE 5

THE MOTION OF AN OBJECT CANNOT BE SPECIFIED UNLESS THIS MOTION CAN BE REFERRED TO SOME OTHER BODY.

FIGURE 6

FORCE IS THAT WHICH CHANGES THE STATE OF MOTION OF A BODY.

FIGURE 7

Newton's 1st Law

TERMINAL OBJECTIVES

3/2 A Analyze and interpret a variety of natural phenomena relevant to Newton's First Law of Motion in terms of the First Law.

Please turn now to page 15A of your STUDY GUIDE to continue with your work.

Newton's 2nd Law

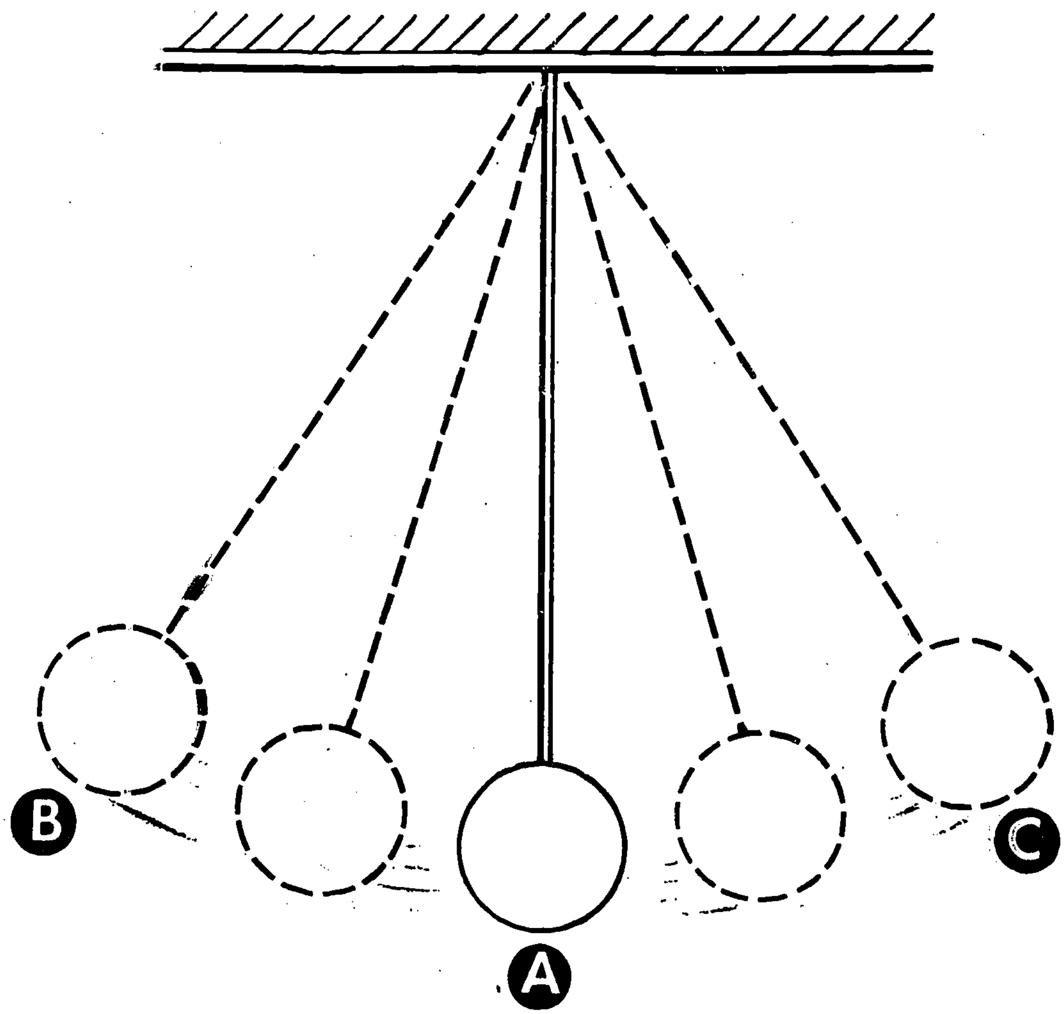


FIGURE 1

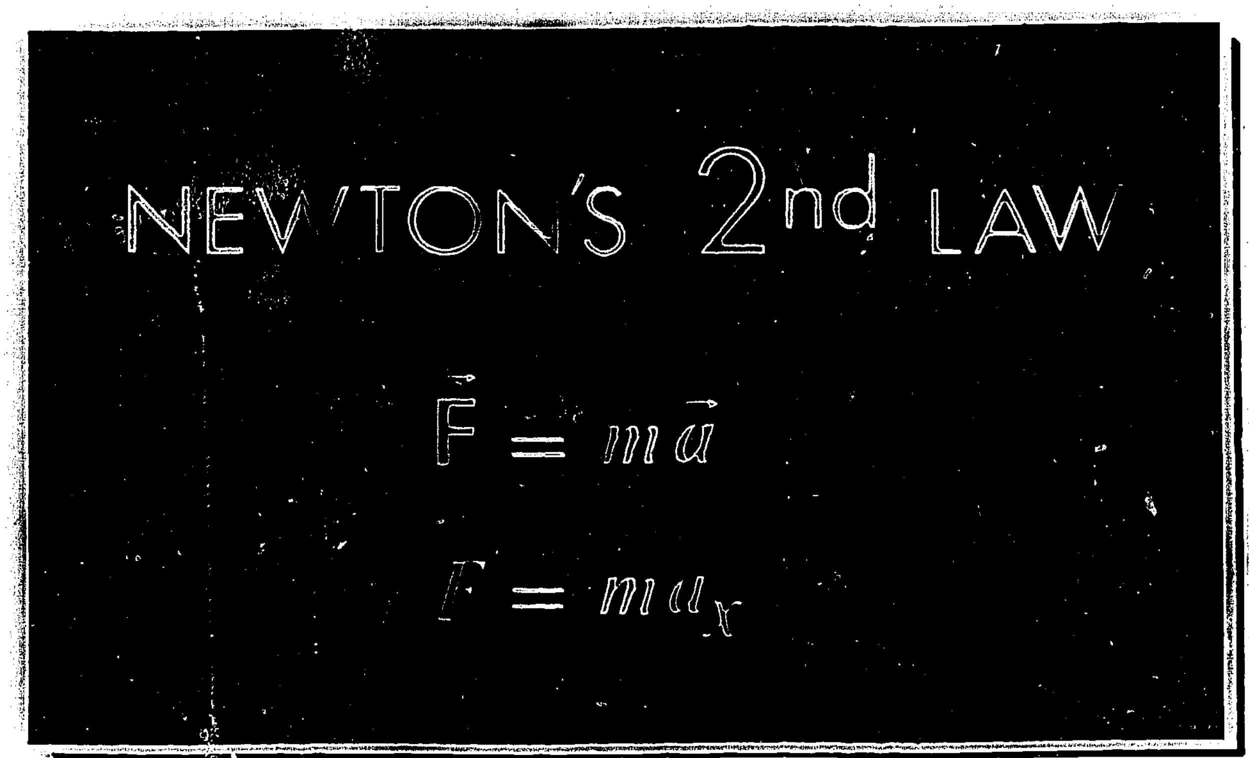


FIGURE 2

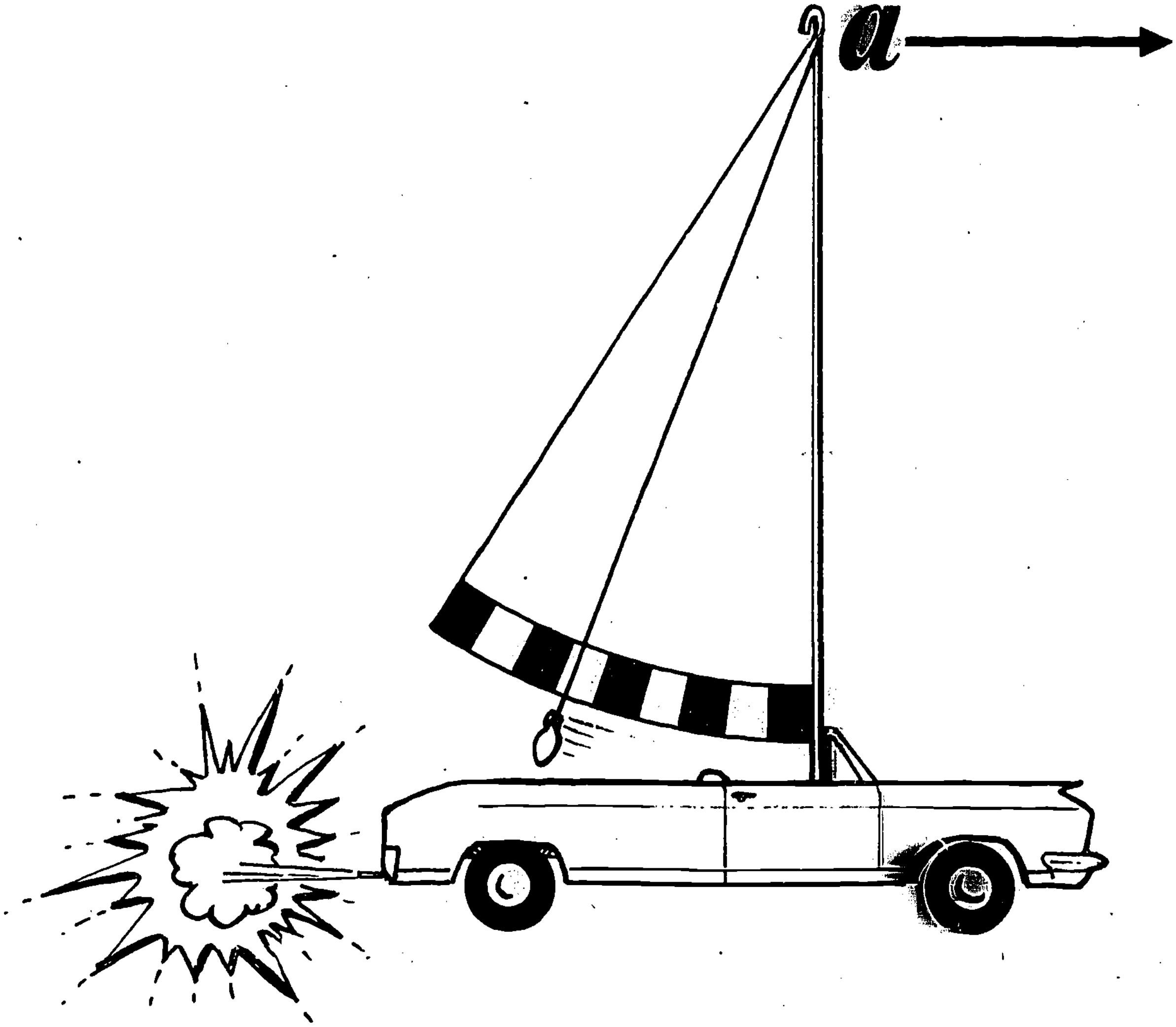


FIGURE 3

FIGURE 4

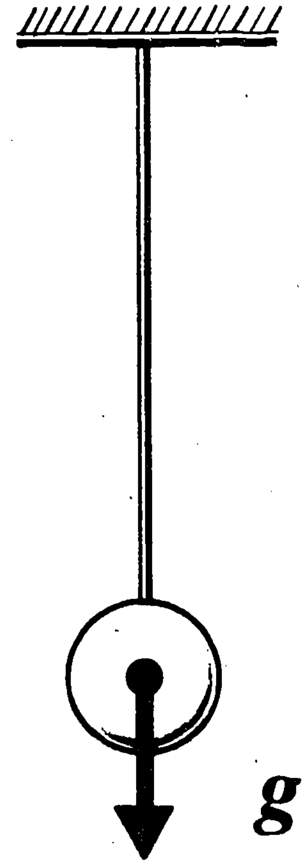
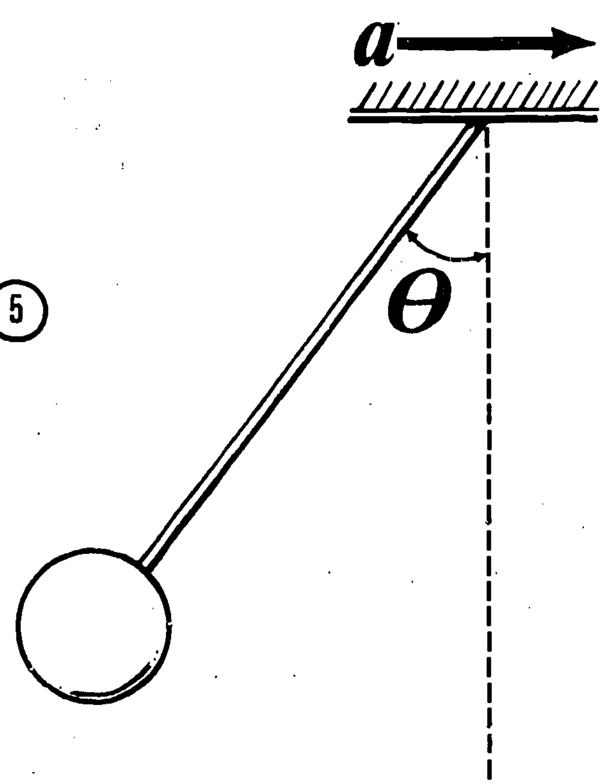


FIGURE 5



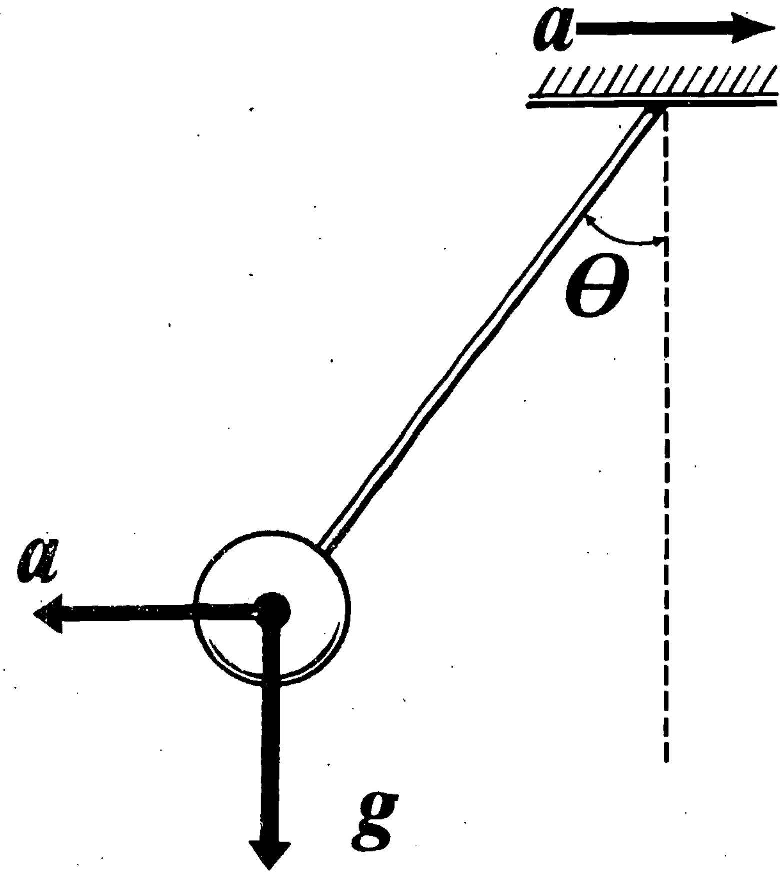


FIGURE 6

$$\tan \theta = \frac{a}{g}$$

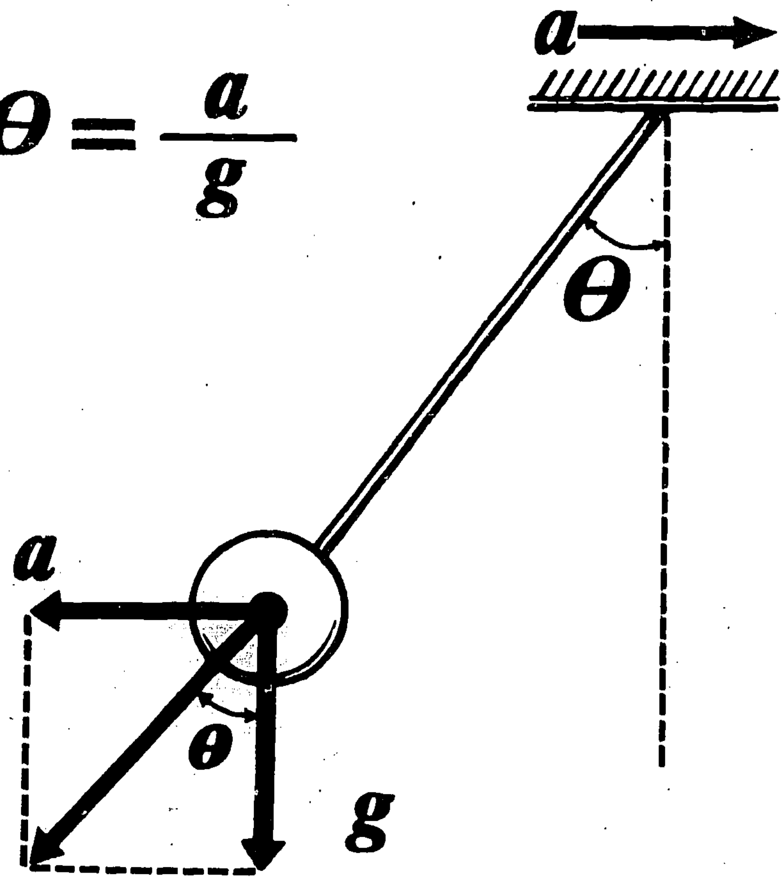


FIGURE 7

$$a = 1.5\ m/sec^2$$

$$F = 0.15\ nt$$

$$m = 0.1\ kg$$

FIGURE 8

Newton's 2nd Law

TERMINAL OBJECTIVES

3/2 B Analyze and interpret a variety of natural phenomena relevant to Newton's Second Law in terms of the Second Law.

Please turn to page 23A of your STUDY GUIDE to continue with your work.

Newton's 3rd Law

IF BODY A EXERTS A FORCE ON BODY B, THEN BODY B EXERTS A FORCE OF EQUAL MAGNITUDE, OPPOSITELY DIRECTED, ON BODY A

FIGURE 1

NEWTON'S THIRD LAW OF MOTION

$$F = -R$$

FIGURE 2

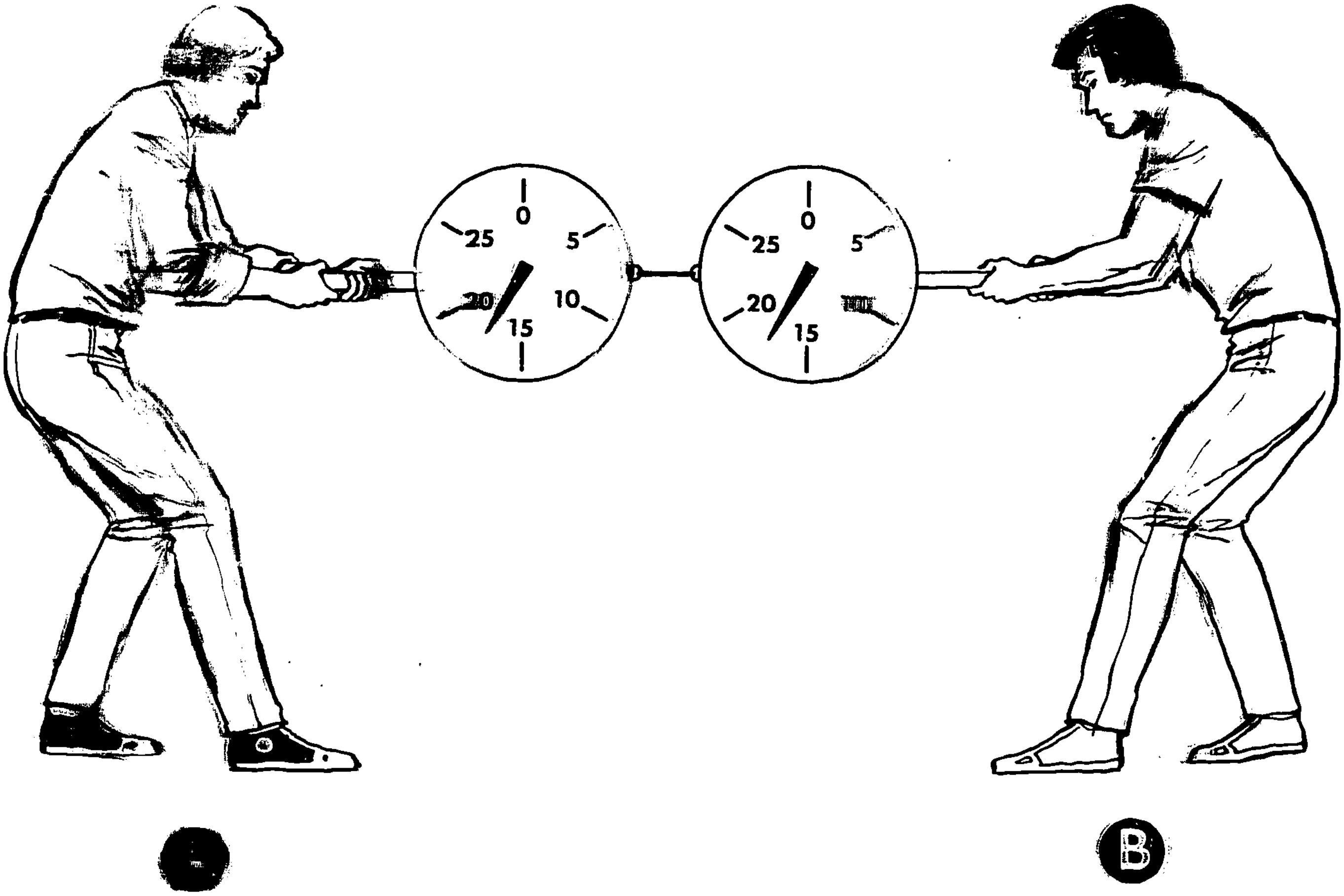


FIGURE 3

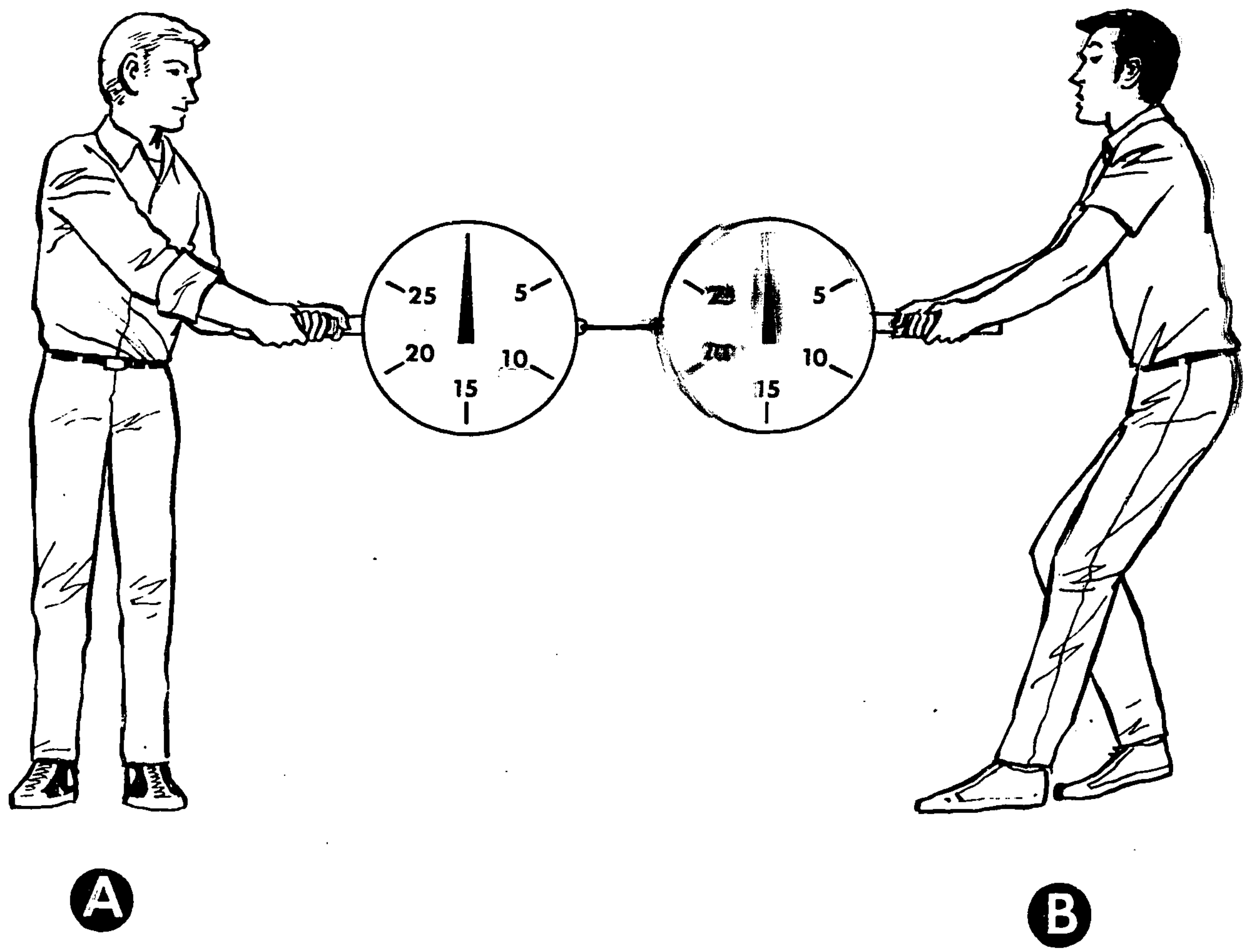


FIGURE 4

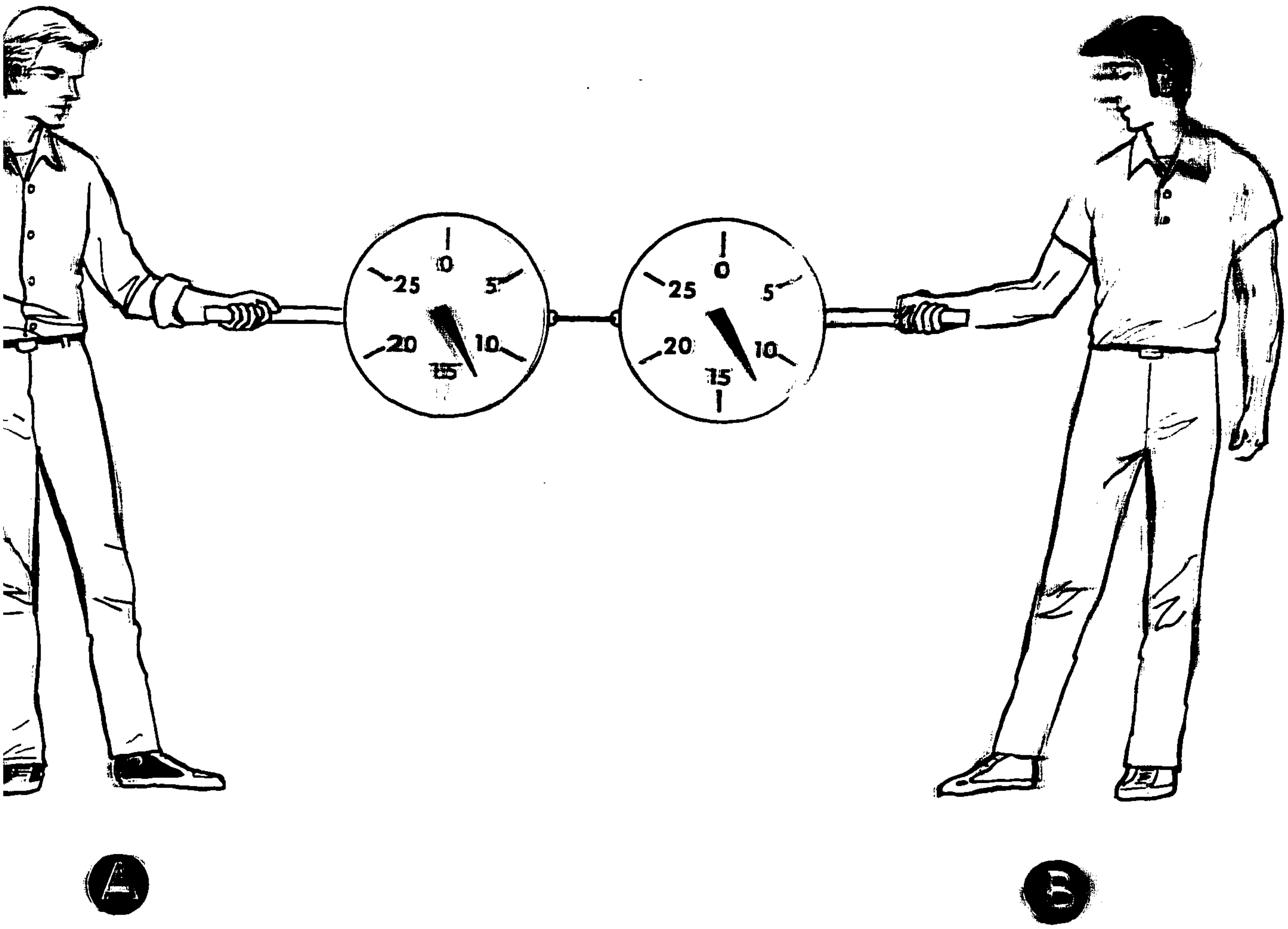


FIGURE 5

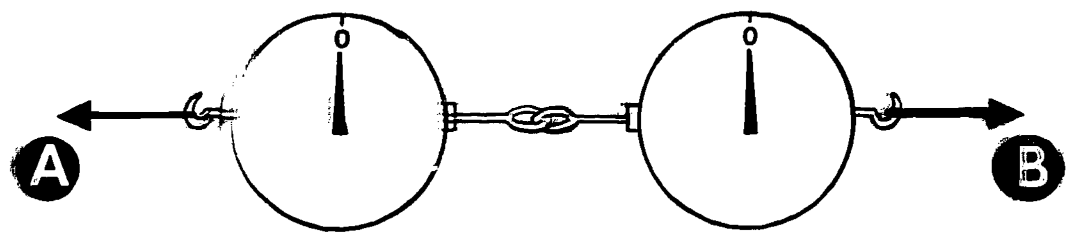


FIGURE 6

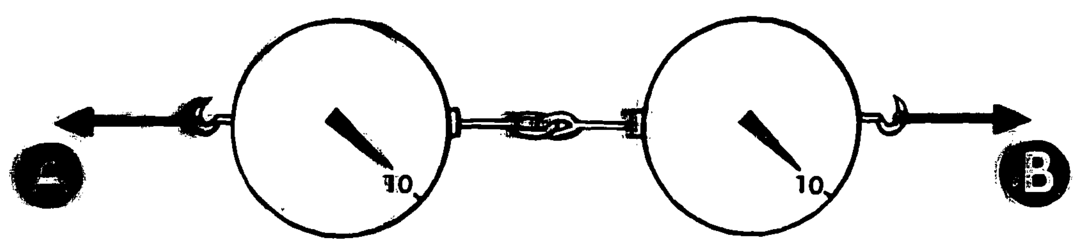


FIGURE 7

Newton's 3rd Law

TERMINAL OBJECTIVES

3/2 C Analyze and interpret a variety of natural phenomena relevant to Newton's Third Law of Motion in terms of the Third Law.

Please turn to page 35A of your STUDY GUIDE to continue with your work.

ATWOOD'S MACHINE

ATWOOD'S ORIGINAL MACHINE

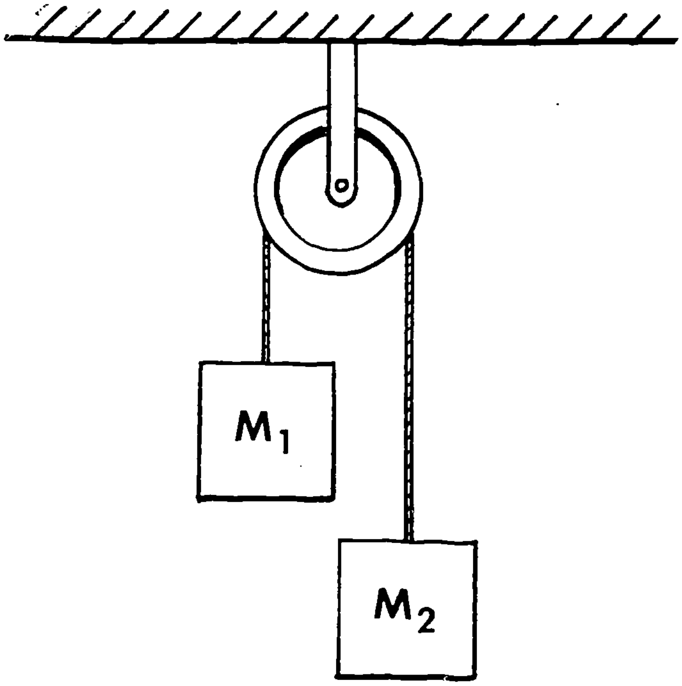


FIGURE 1

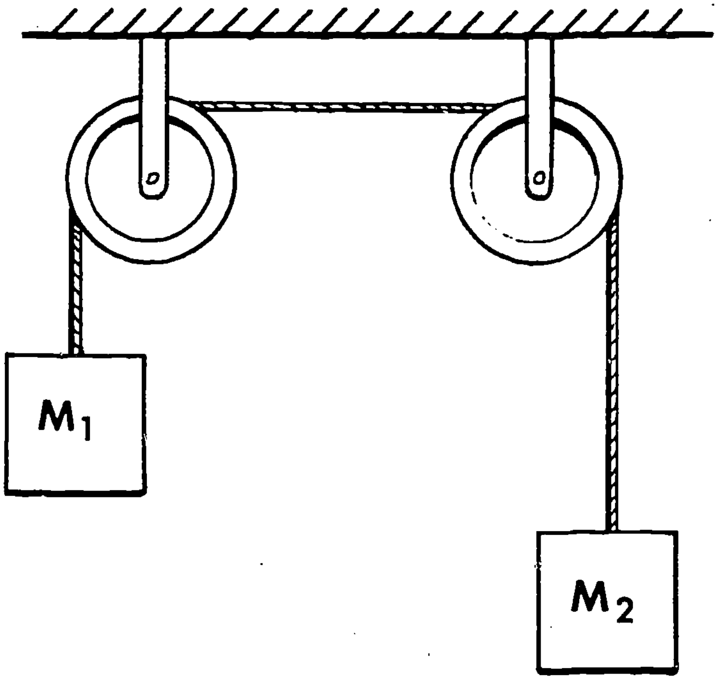


FIGURE 2

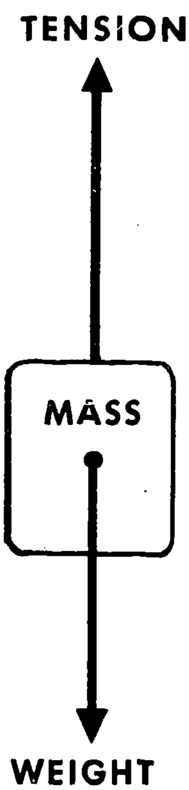


FIGURE 3

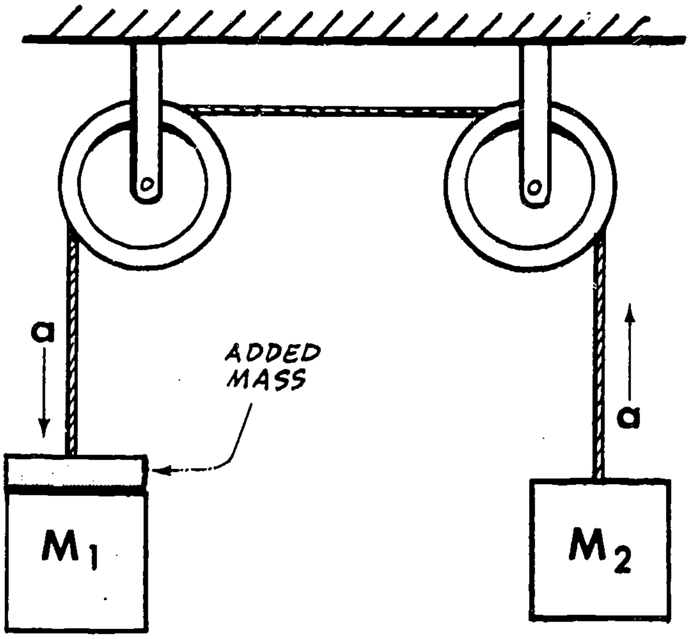


FIGURE 4

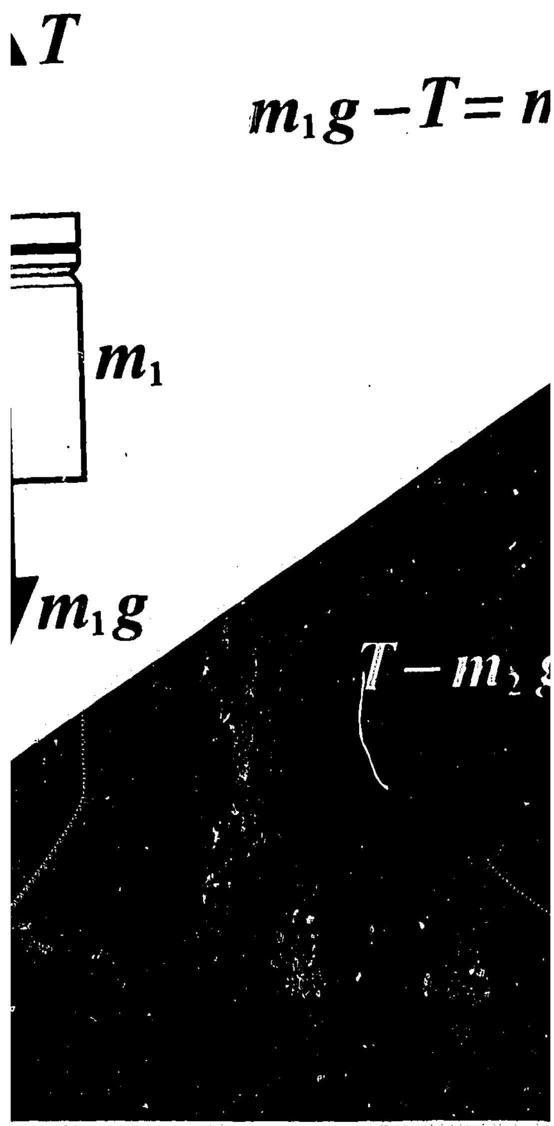


FIGURE 5

$$m_1 g - \cancel{T} = m_1 a$$

$$\cancel{T} - m_2 g = m_2 a$$

ADD

$$m_1 g - m_2 g = m_1 a + m_2 a$$

$$a = \frac{m_1 - m_2}{m_1 + m_2} \cdot g$$

FIGURE 6

$$T - m_2 g = m_2 a$$

$$a = \frac{m_1 - m_2}{m_1 + m_2} \cdot g$$

So

$$T = m_2 \frac{m_1 - m_2}{m_1 + m_2} \cdot g + m_2 g$$

FIGURE 7

$$T = 2\,\frac{m_1\ m_2}{m_1+m_2}\cdot g$$

FIGURE 8

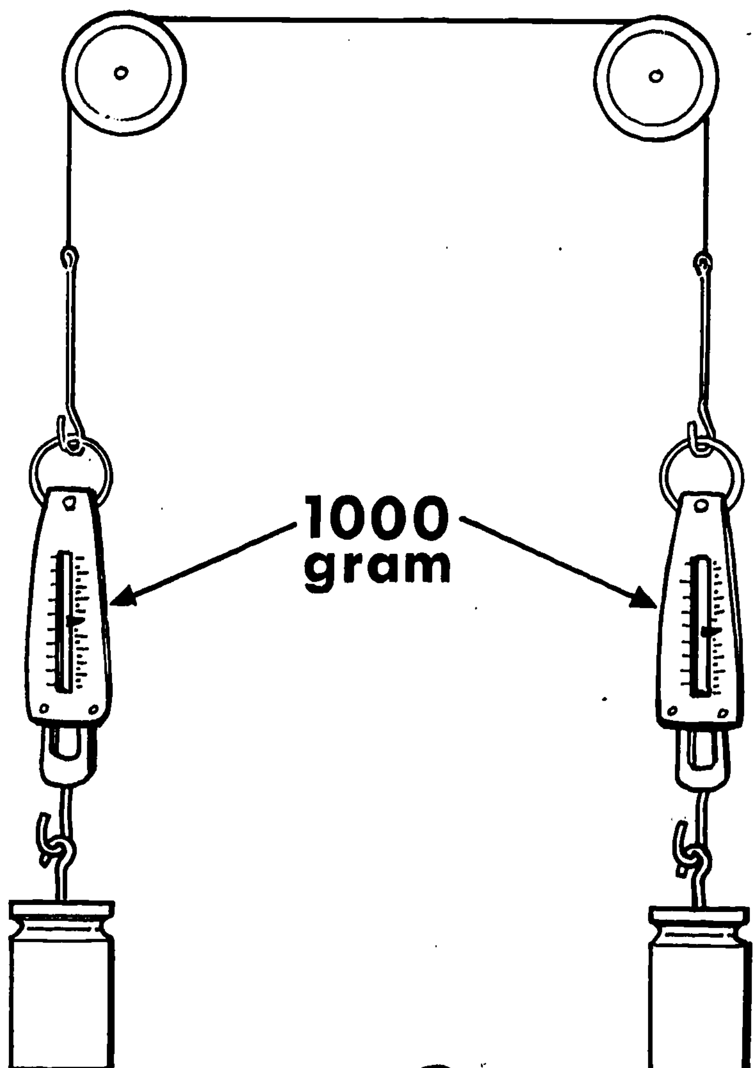


FIGURE 9

$$T = 2\,\frac{m_1 \quad m_2}{m_1 + m_2}\cdot g$$

$$= 2\,\frac{1000 \times 1000}{1000 + 1000}\cdot g$$

$$= 1000\cdot g$$

FIGURE 10

$$T = 2\,\frac{m_1 \quad m_2}{m_1 + m_2}\cdot g$$

$$= 2\,\frac{1400 \times 1000}{1400 + 1000}\cdot g$$

$$= 1170\cdot g$$

FIGURE 11

ATWOOD'S MACHINE

TERMINAL OBJECTIVES

3/3 D Apply the "free body" approach to problem solutions.

Please turn to page 13A of your STUDY GUIDE to continue with your work.

CHARACTERISTICS OF CIRCULAR MOTION

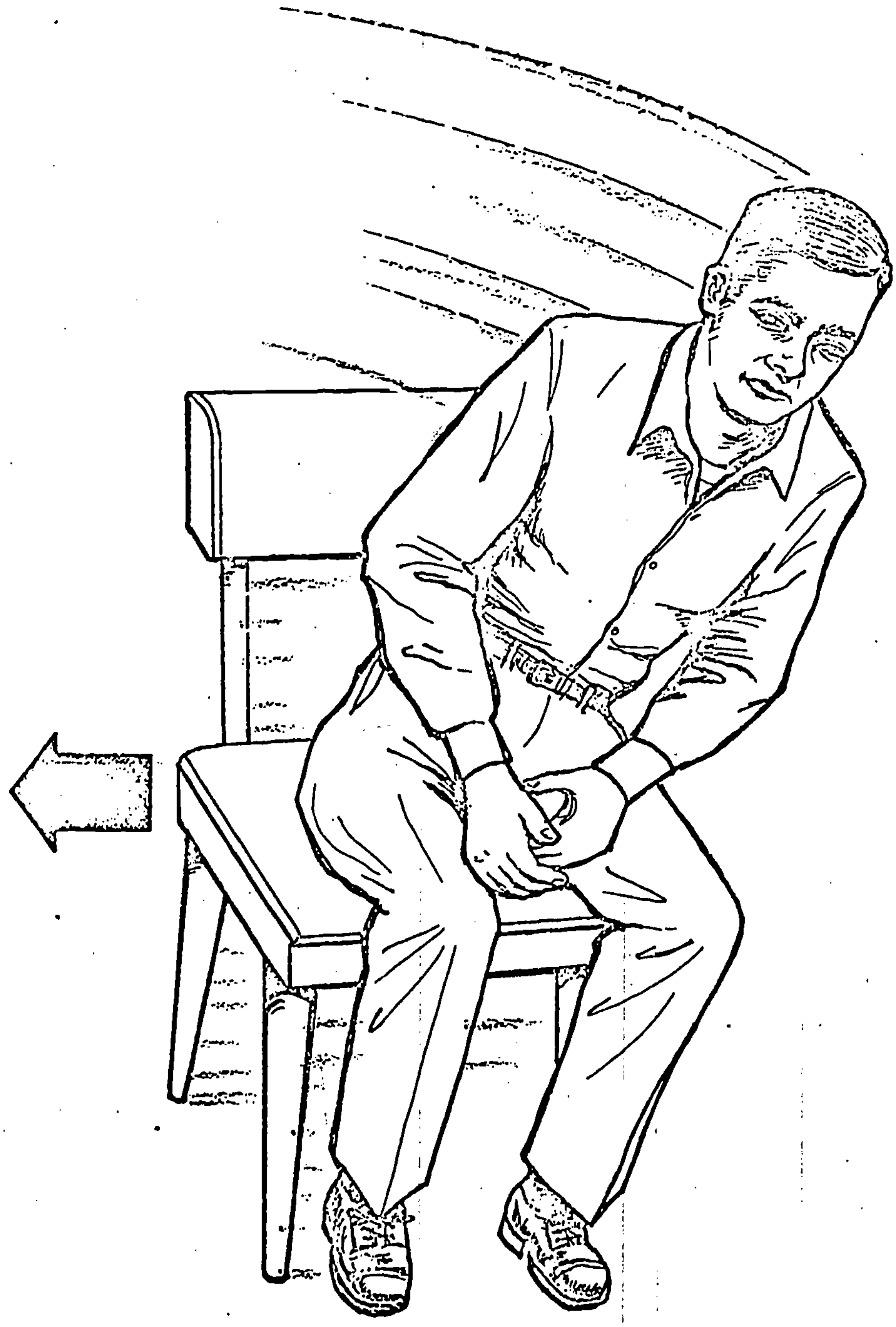


FIGURE 1

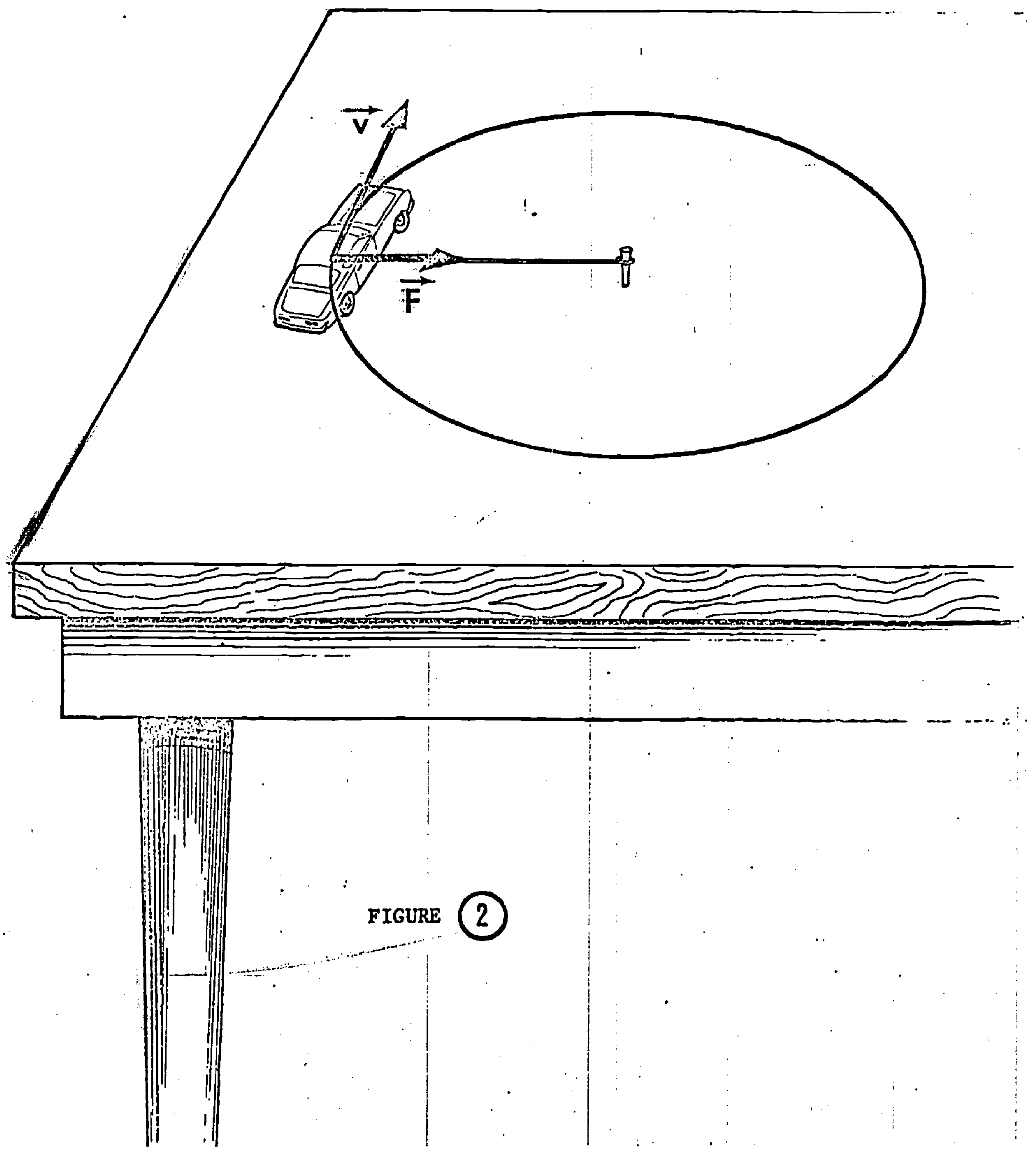


FIGURE 2

CENTRIPETAL & CENTRIFUGAL FORCES IN CIRCULAR MOTION

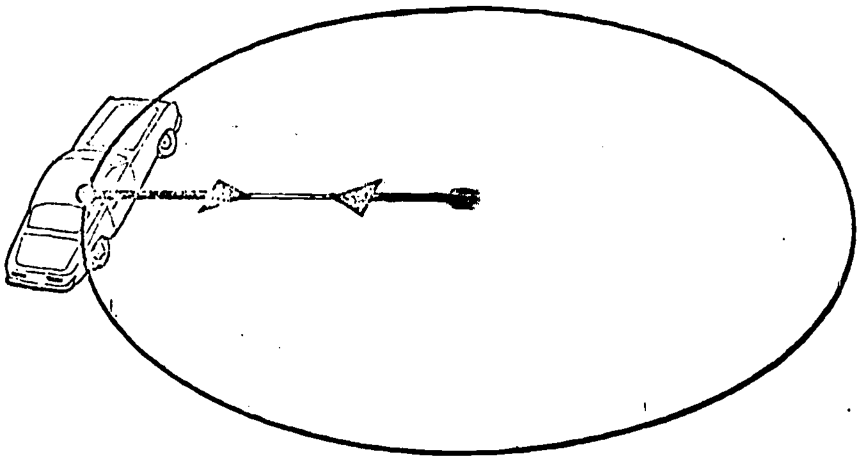


FIGURE 3

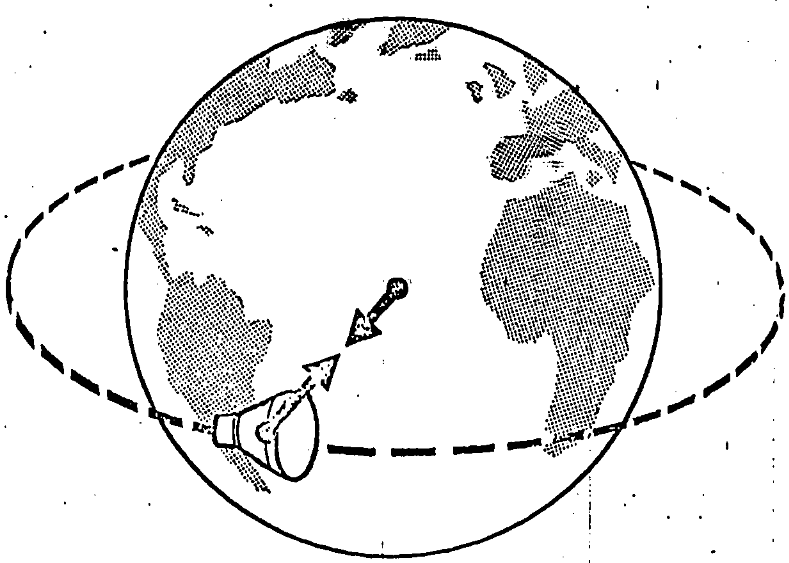


FIGURE 4

Centripetal Acceleration

$$a_c = \frac{v^2}{r}$$

Substituted into the Equation of Motion

$$F = ma$$

Yields an Equation for Circular Motion

$$F_c = \frac{mv^2}{r}$$

FIGURE 5

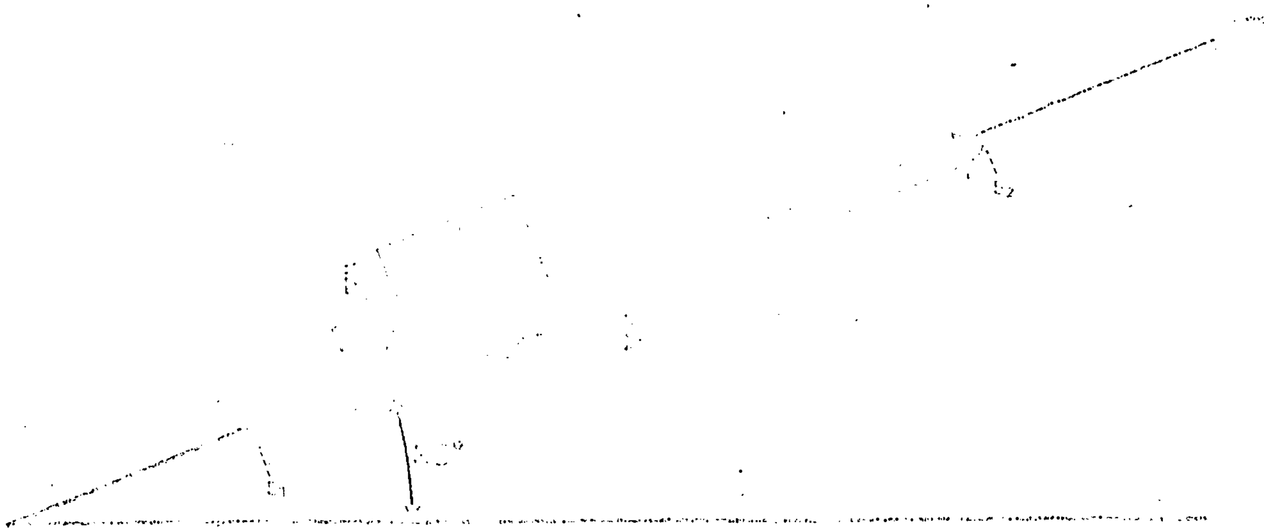


FIGURE 1

FIGURE 2

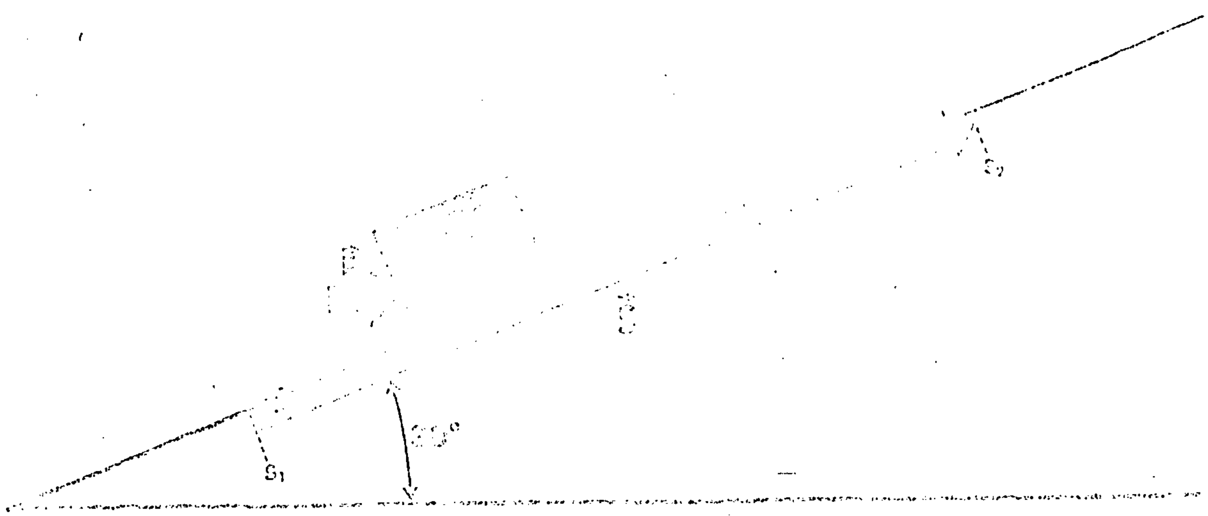


FIGURE 3

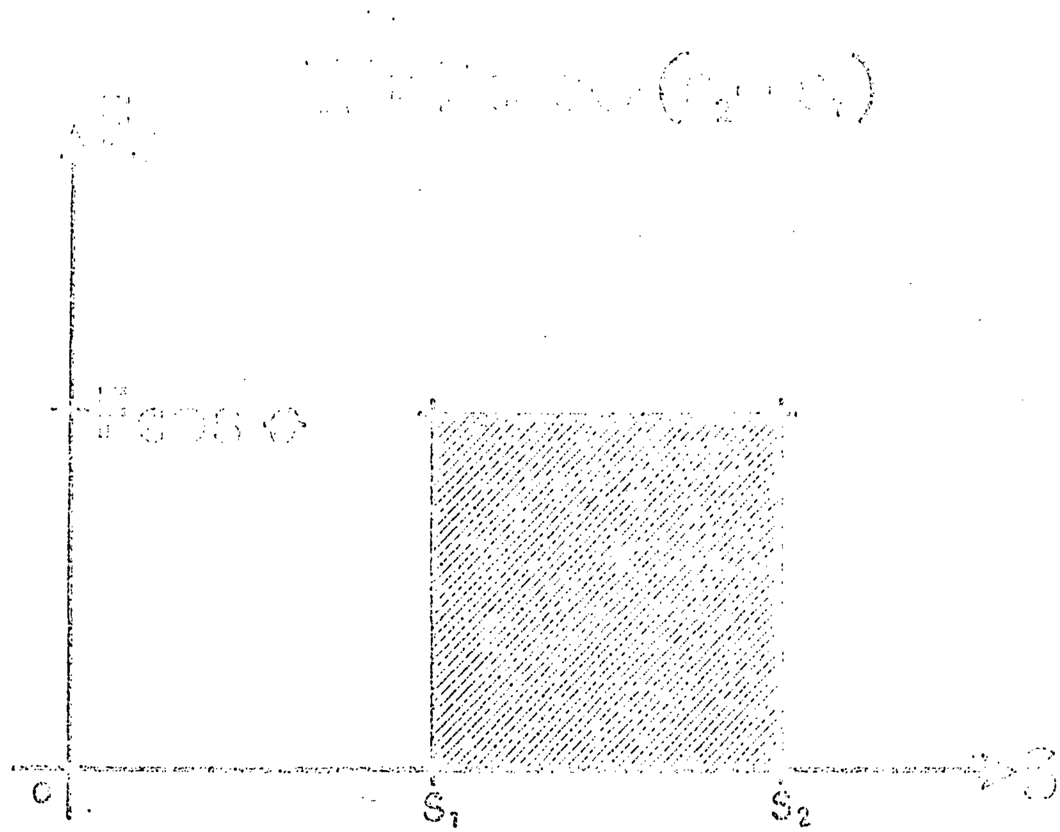


FIGURE 4

[illegible]

$$= F \cdot \int_{S_1}^{S_2} dS$$

$$= F \quad S \Big|_{S_1}^{S_2}$$

$$= F \left(S_2 - S_1 \right)$$

FIGURE 5

$$= F \cos \theta_1 \int_{S_1}^{S_2} ds$$

$$= F \cos \theta_1 \, s \Big|_{S_1}^{S_2}$$

$$= F \cos \theta_1 (S_2 - S_1)$$

FIGURE 6

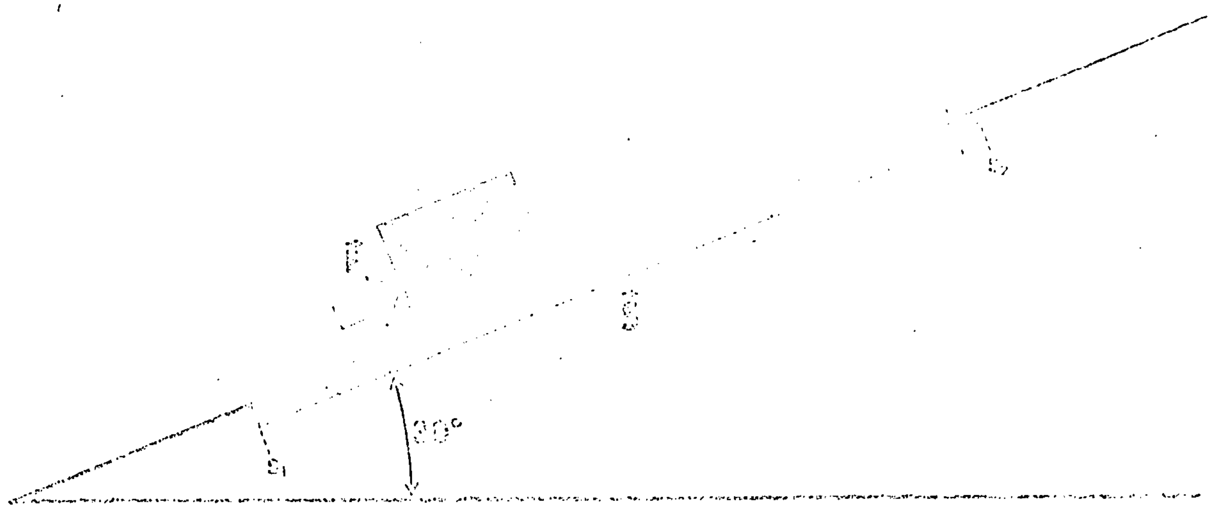


FIGURE 7

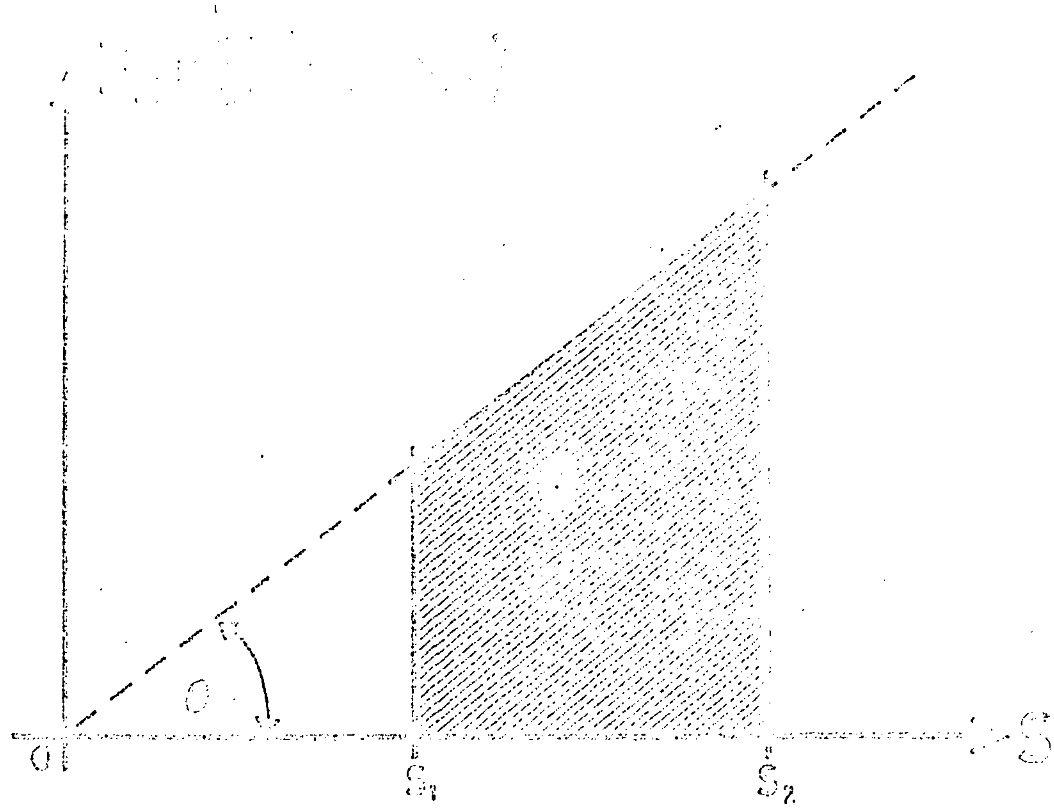


FIGURE 8

$$W = \int_{s_1}^{s_2} k s \cos\theta \, ds$$

$$= k \cos\theta \int_{s_1}^{s_2} s \, ds$$

$$= \frac{1}{2} k \cos\theta \left(s_2^2 - s_1^2\right)$$

FIGURE 9

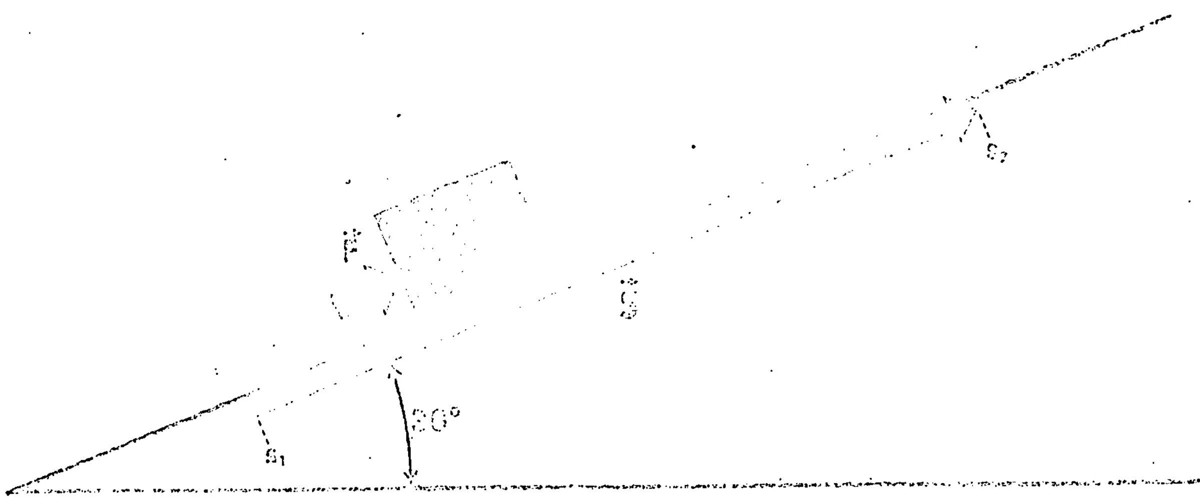


FIGURE 10

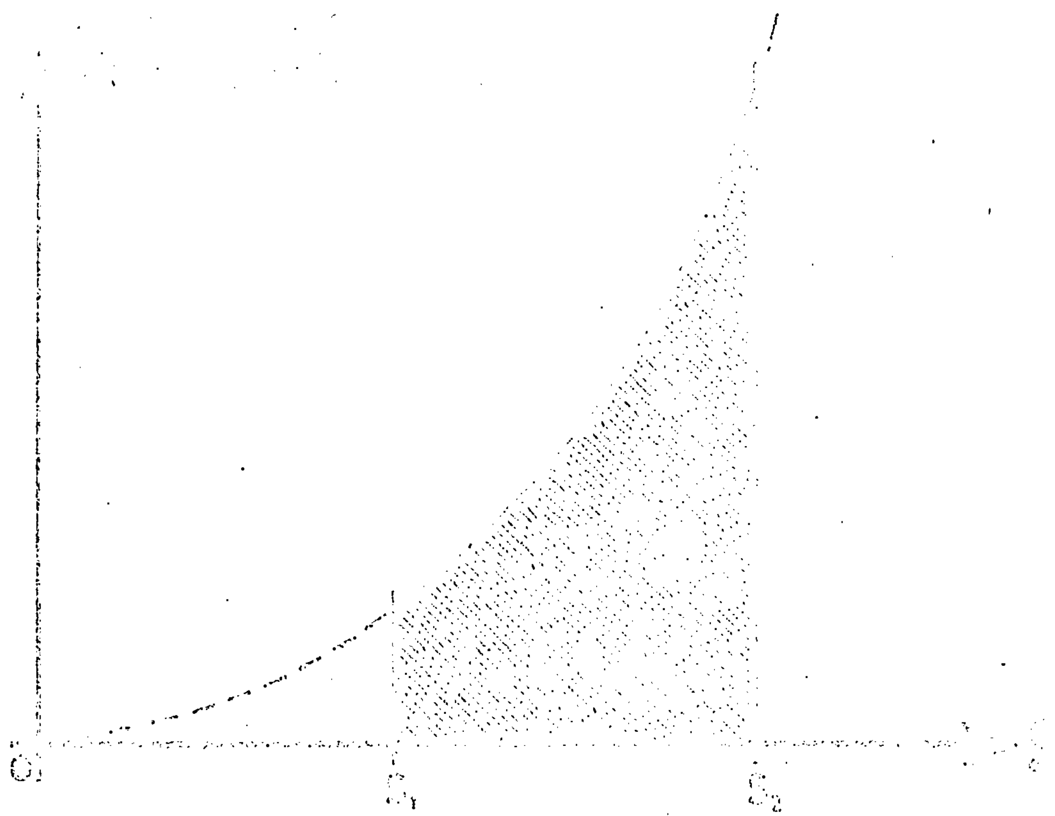


FIGURE 11

$$W = \int_{S_1}^{S_2} ps^2\,ds$$

FIGURE 12

[illegible]

TERMINAL OBJECTIVES

5/1 B Calculate work associated with variable forces.

Please turn to page 26A of your STUDY GUIDE to continue with your work.

KINETIC ENERGY

$$\vec{F} = m\vec{a}$$

$$= m\,\frac{d\vec{v}}{dt}$$

FIGURE 1

WORK DONE ON BODY

$$= \int \vec{F} \cdot d\vec{s}$$

$\vec{F} =$ resultant force on body

FIGURE 2

$$W = \int_{S_1}^{S_2} \vec{F} \cdot d\vec{s}$$

$$= \int_{S_1}^{S_2} m \frac{d\vec{v}}{dt} \cdot d\vec{s}$$

FIGURE 3

$$W = \int_{S_1}^{S_2} \vec{F} \cdot d\vec{s}$$

$$= \int_{S_1}^{S_2} m \, d\vec{v} \cdot \frac{d\vec{s}}{dt}$$

FIGURE 4

$$W = \int_{S_1}^{S_2} \vec{F} \cdot d\vec{s}$$

$$= \int_{S_1}^{S_2} m \, d\vec{v} \cdot \vec{v}$$

FIGURE 5

$$W = \int_{S_1}^{S_2} \vec{F} \cdot d\vec{s}$$

$$= \int_{S_1}^{S_2} m \, d\vec{v} \cdot \vec{v}$$

$$= \int_{V_1}^{V_2} m \, \vec{v} \cdot d\vec{v}$$

FIGURE 6

KINETIC ENERGY

TERMINAL OBJECTIVES

5/2 D Answer qualitative questions about Kinetic Energy.

Please turn to page 38A of your STUDY GUIDE to continue with your work.

POTENTIAL ENERGY

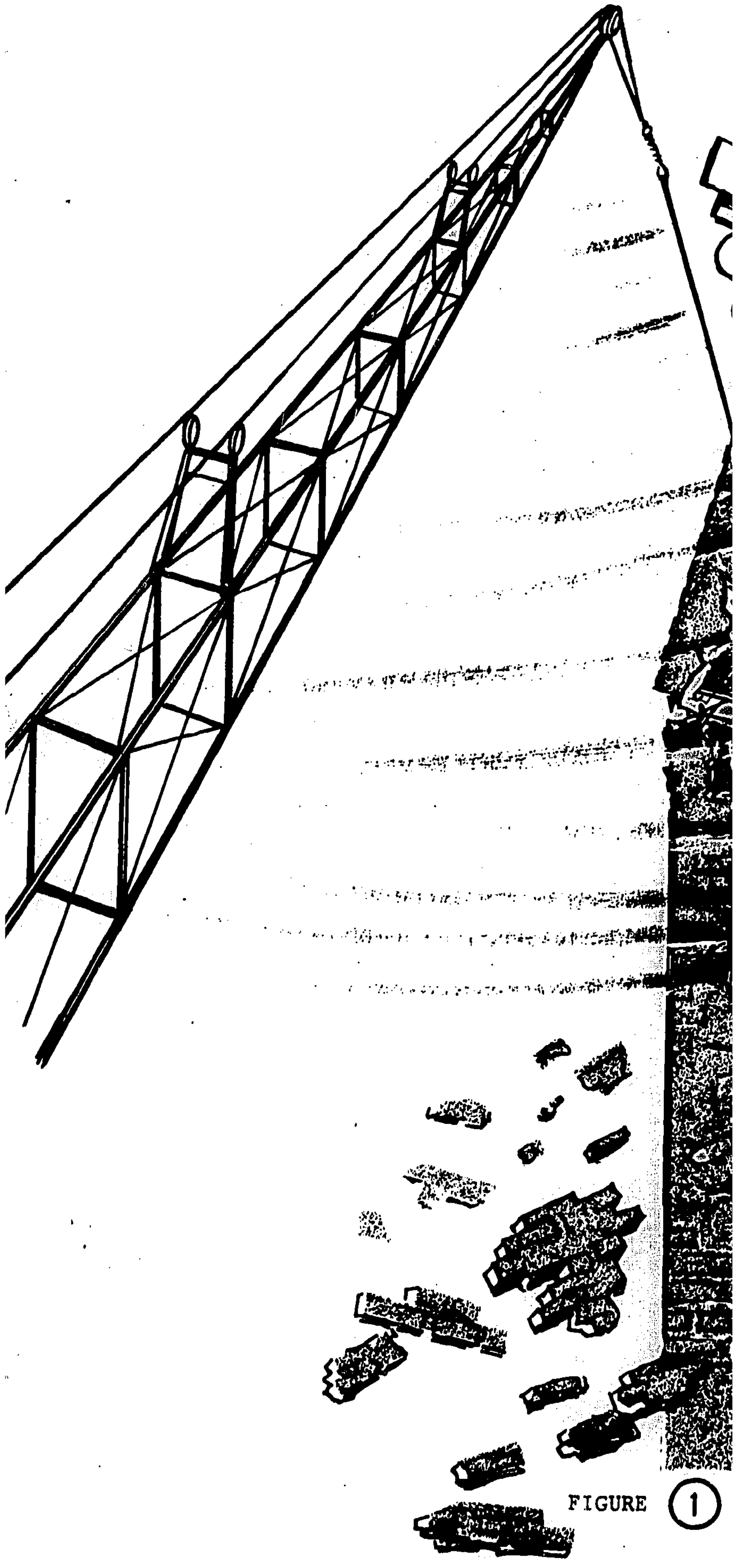


FIGURE 1

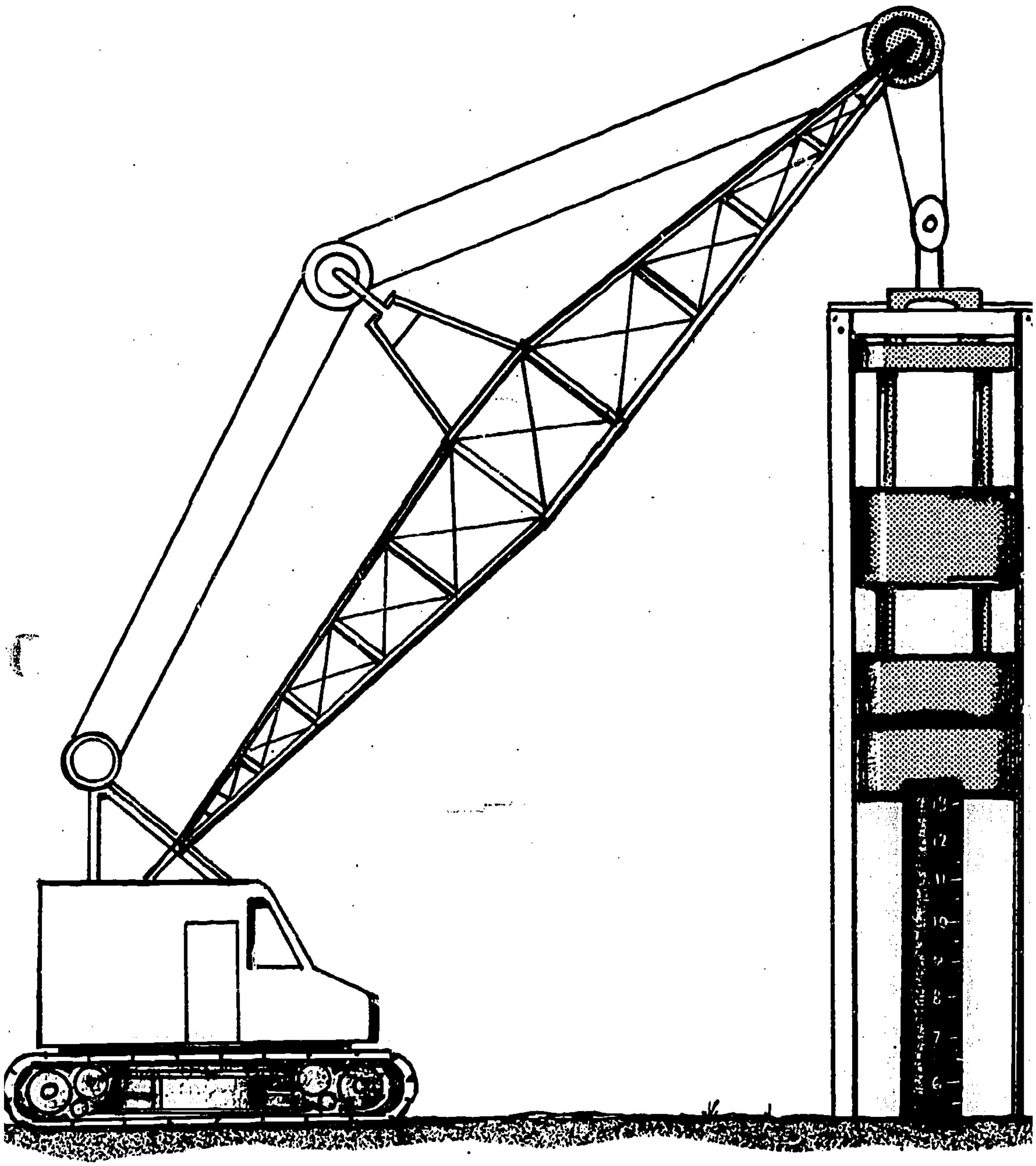
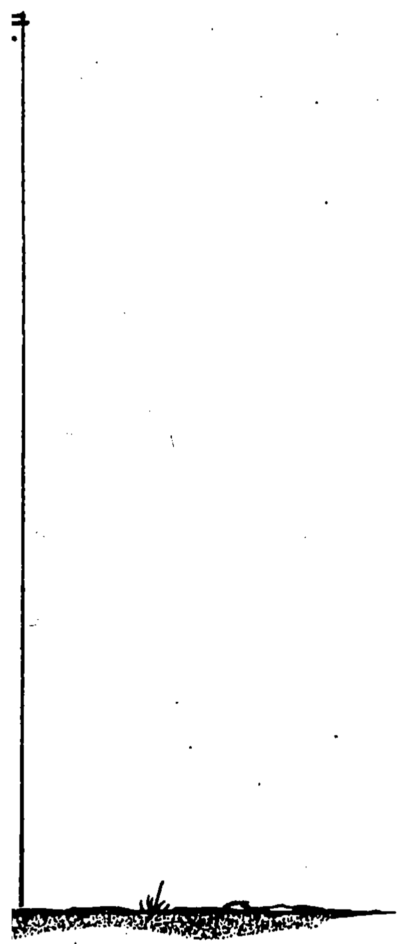


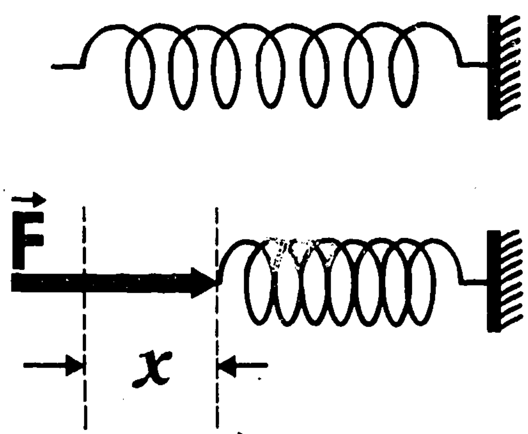
FIGURE 2



POTENTIAL ENERGY

= Energy of
Position
or state

FIGURE 3



$$\vec{F} = k\vec{x}$$

FIGURE 4

$$W = \int_{x_1}^{x_2} \vec{F}\, d\vec{x}$$

FIGURE 5

$$W = \int_{x_1}^{x_2} F\, dx$$

FIGURE 6

$$W = \int_{x_1}^{x_2} F\, dx = \int_{x_1}^{x_2} kx\, dx$$

FIGURE 7

$$W = \int_{x_1}^{x_2} F\, dx = \int_{x_1}^{x_2} kx\, dx = \frac{1}{2}kx_2^2 - \frac{1}{2}kx_1^2$$

FIGURE 8

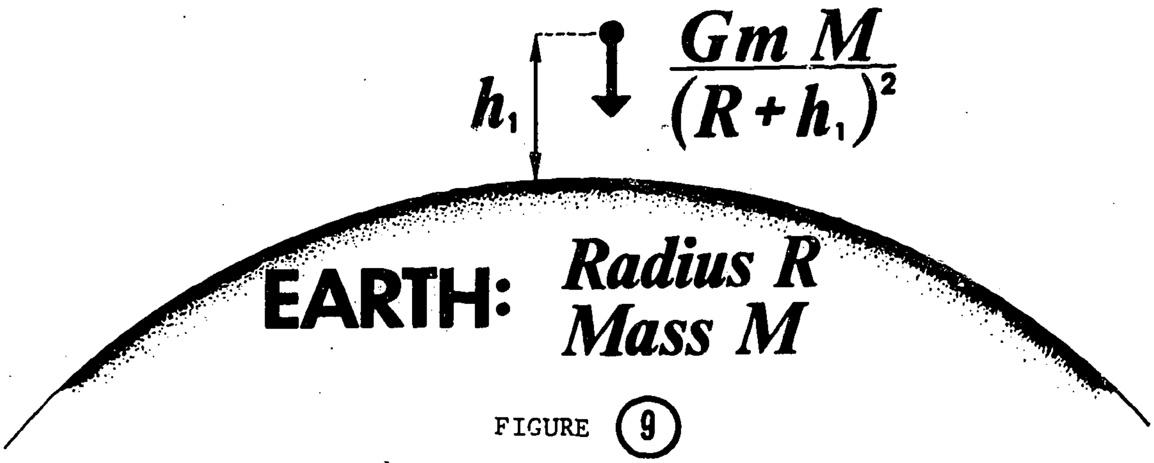


FIGURE (9)

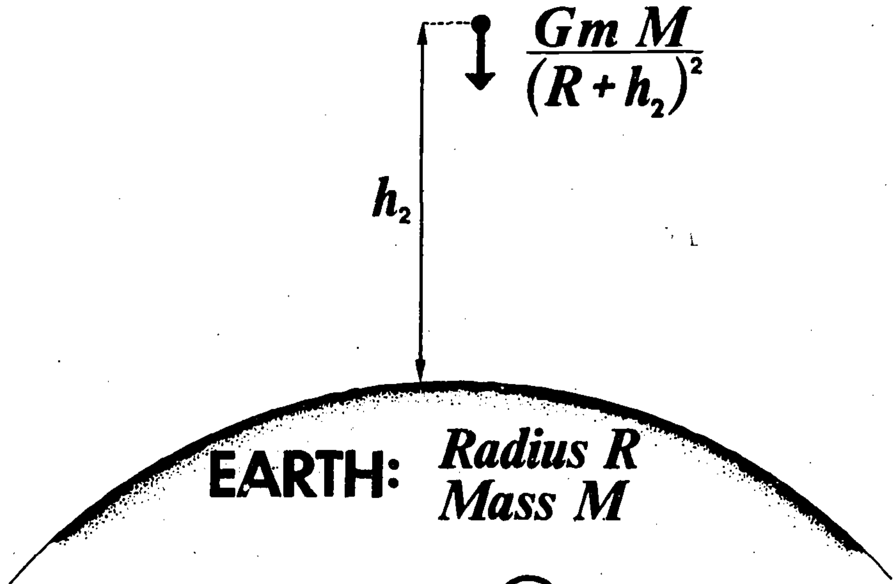


FIGURE (10)

CHANGE IN POTENTIAL ENERGY

$$= \int \vec{\mathbf{F}} \cdot d\vec{s}$$

$$= \int_{h_1}^{h_2} \frac{GmM\,dh}{(R+h)^2}$$

FIGURE (11)

FIGURE 12

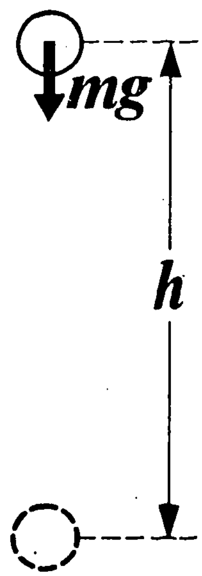


FIGURE 13

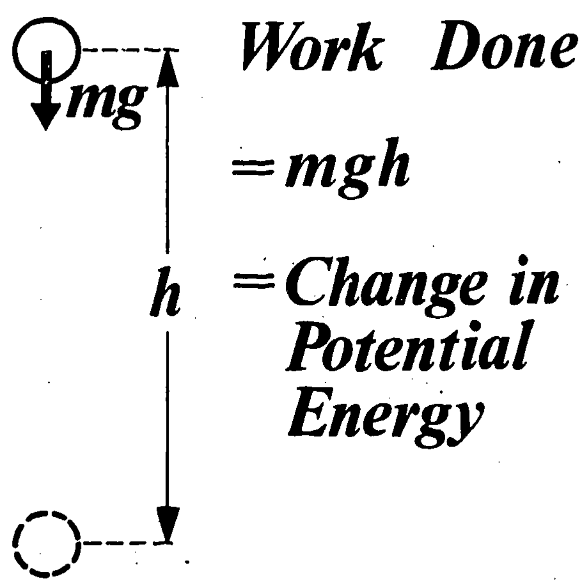


FIGURE 14

POTENTIAL ENERGY

TERMINAL OBJECTIVES

5/3 A Use the concept of potential energy for objects near the surface of the Earth and for springs.

Please turn to page 33A of your STUDY GUIDE to continue with your work.

CONSERVATION OF ENERGY

$$\int F \quad dx$$

$$= \int m \, \frac{dv}{dt} \, dx$$

$$= \Delta \frac{1}{2} mv^2$$

FIGURE 1

WORK DONE
= CHANGE IN
KINETIC ENERGY
(free body)

FIGURE 2

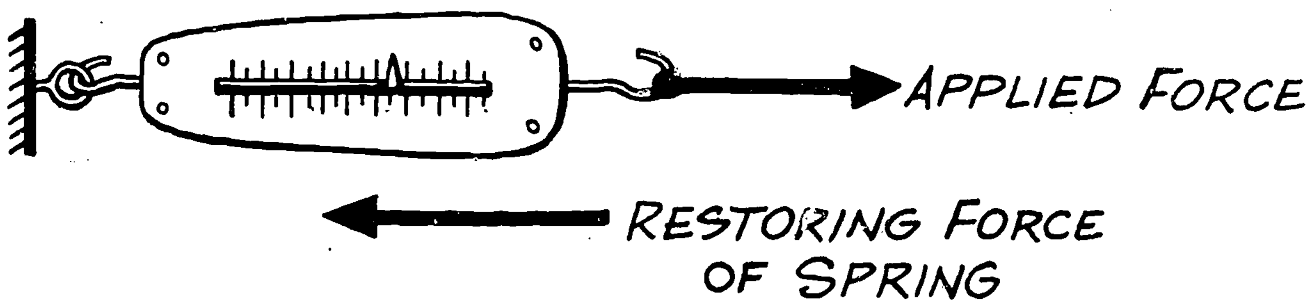


FIGURE 3

WORK DONE IN COMPRESSING SPRING

$$= \int F\,dx = \int_0^x kx\,dx$$

$$= \frac{1}{2}kx^2$$

FIGURE 4

POTENTIAL ENERGY

$$= \frac{1}{2}kx^2$$

FIGURE 5

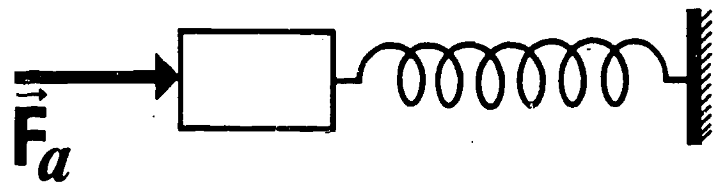


FIGURE 6

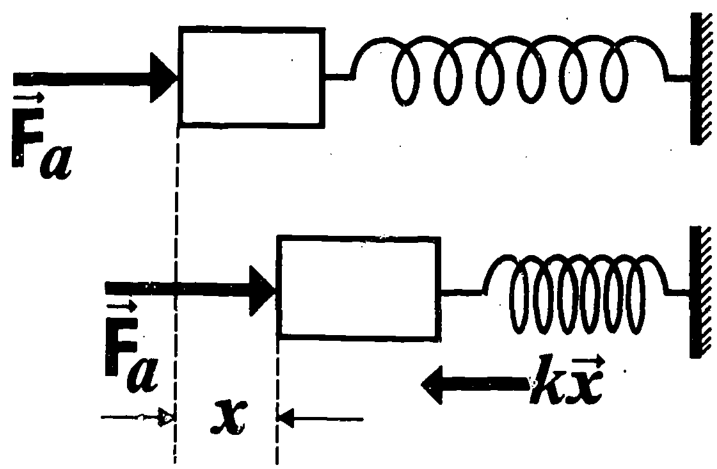
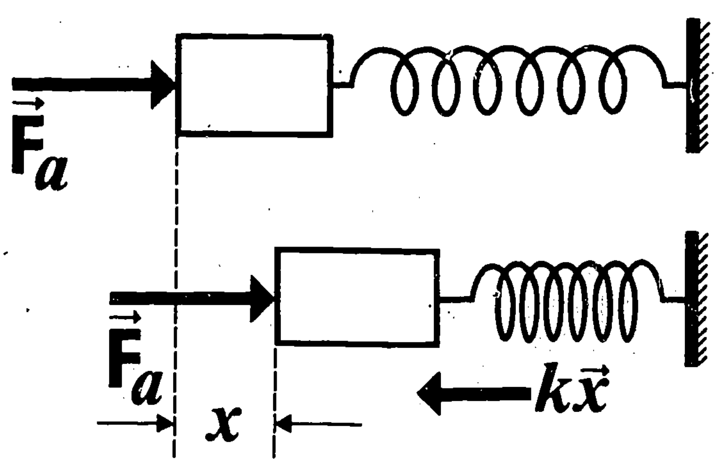
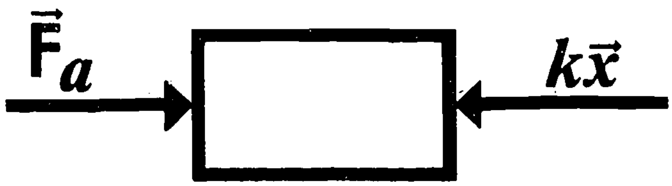


FIGURE 7



RESULTANT $= F_a - kx$

FIGURE 8



Free Body Diagram

FIGURE 9

WORK DONE

$$= \int F\,dx$$

$$\Delta\,P.E. = \int_0^x kx\,dx$$

FIGURE 10

WORK DONE

$$= \int F\,dx$$

$$\Delta\,P.E. = \int_0^x kx\,dx$$

$$\Delta\,K.E. = \int_0^x (F_a - kx)\,dx$$

FIGURE 11

EXTERNAL WORK DONE

CHANGE in P.E.

CHANGE IN K.E.

TOTAL ENERGY

FIGURE 12

NO EXTERNAL WORK DONE

TOTAL ENERGY

FIGURE 13

Negative

CHANGE IN P.E.

Positive

CHANGE IN K.E.

FIGURE 14

CONSERVATION OF ENERGY

TERMINAL OBJECTIVES

5/2 C Answer questions pertaining to the statement of conservation of energy.

5/3 B Apply conservation of energy to a simple pendulum.

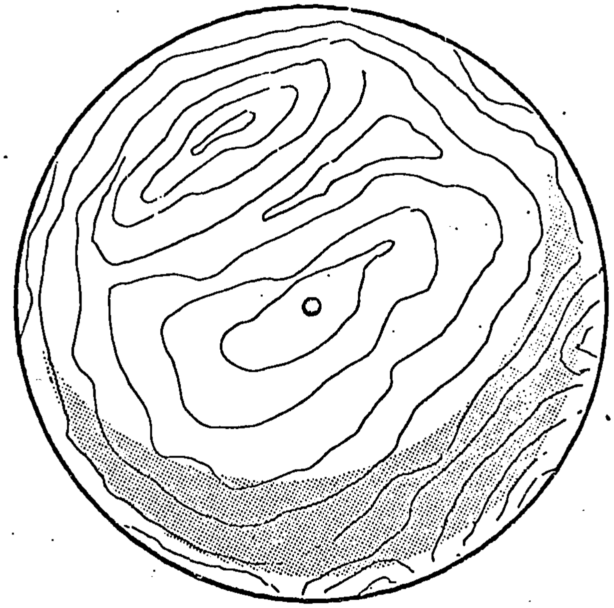
5/3 C Demonstrate a knowledge of specifies required for the application of the Conservation of Energy theorem.

Please turn to page 34A of your STUDY GUIDE to continue with your work.

MOVEMENT OF CENTER OF MASS

CENTER OF MASS

(a) for a solid ball



(b) for a hollow ball

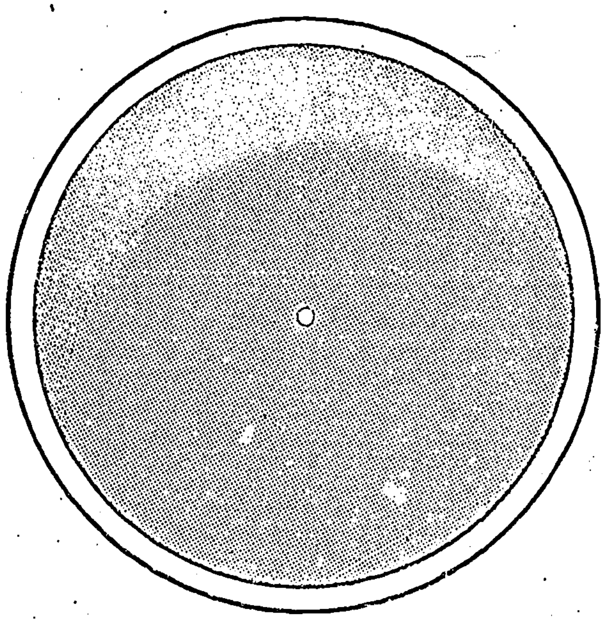


FIGURE 1

EQUAL MASS CARS

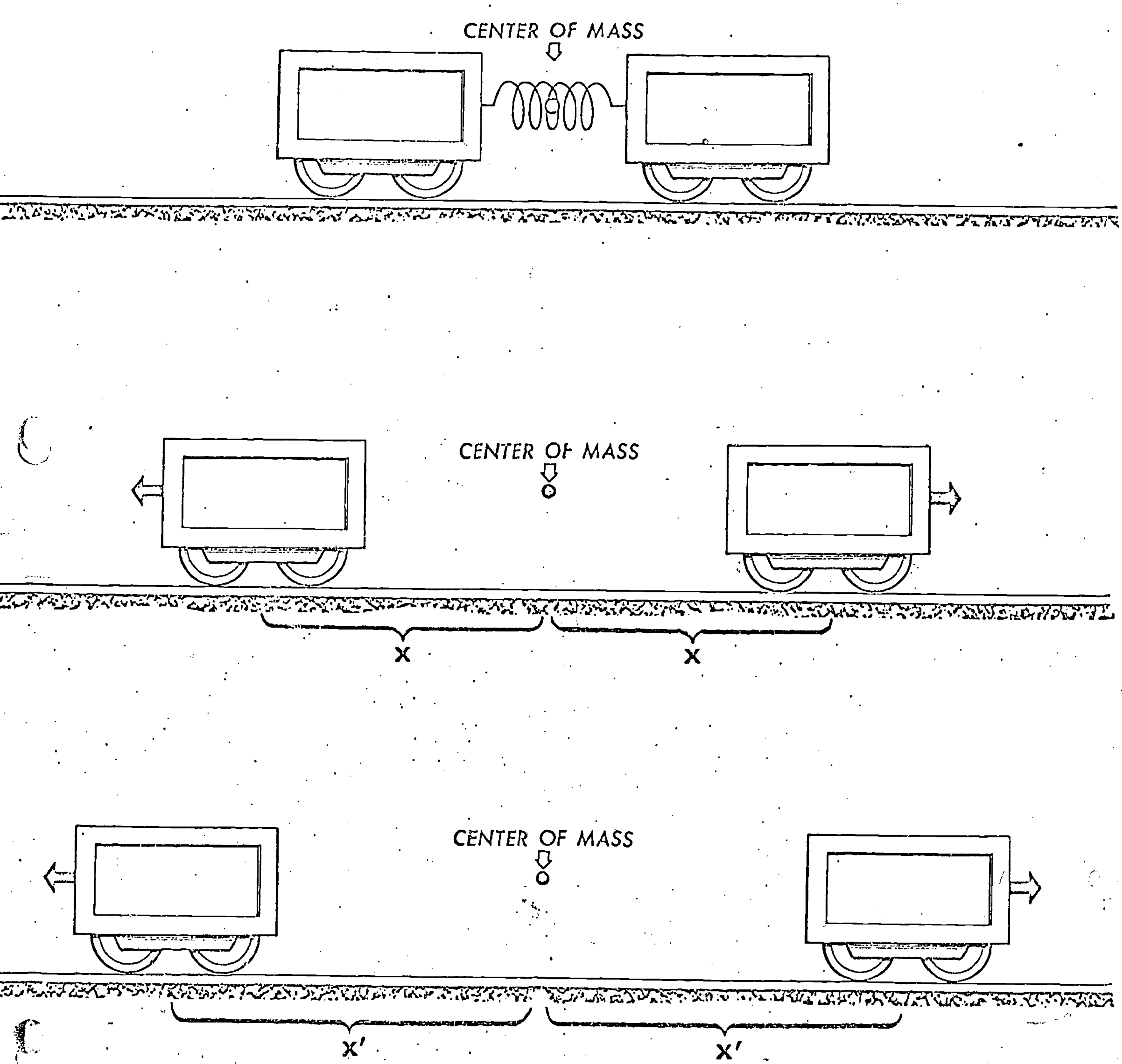


FIGURE (2)

UNEQUAL MASS CARS

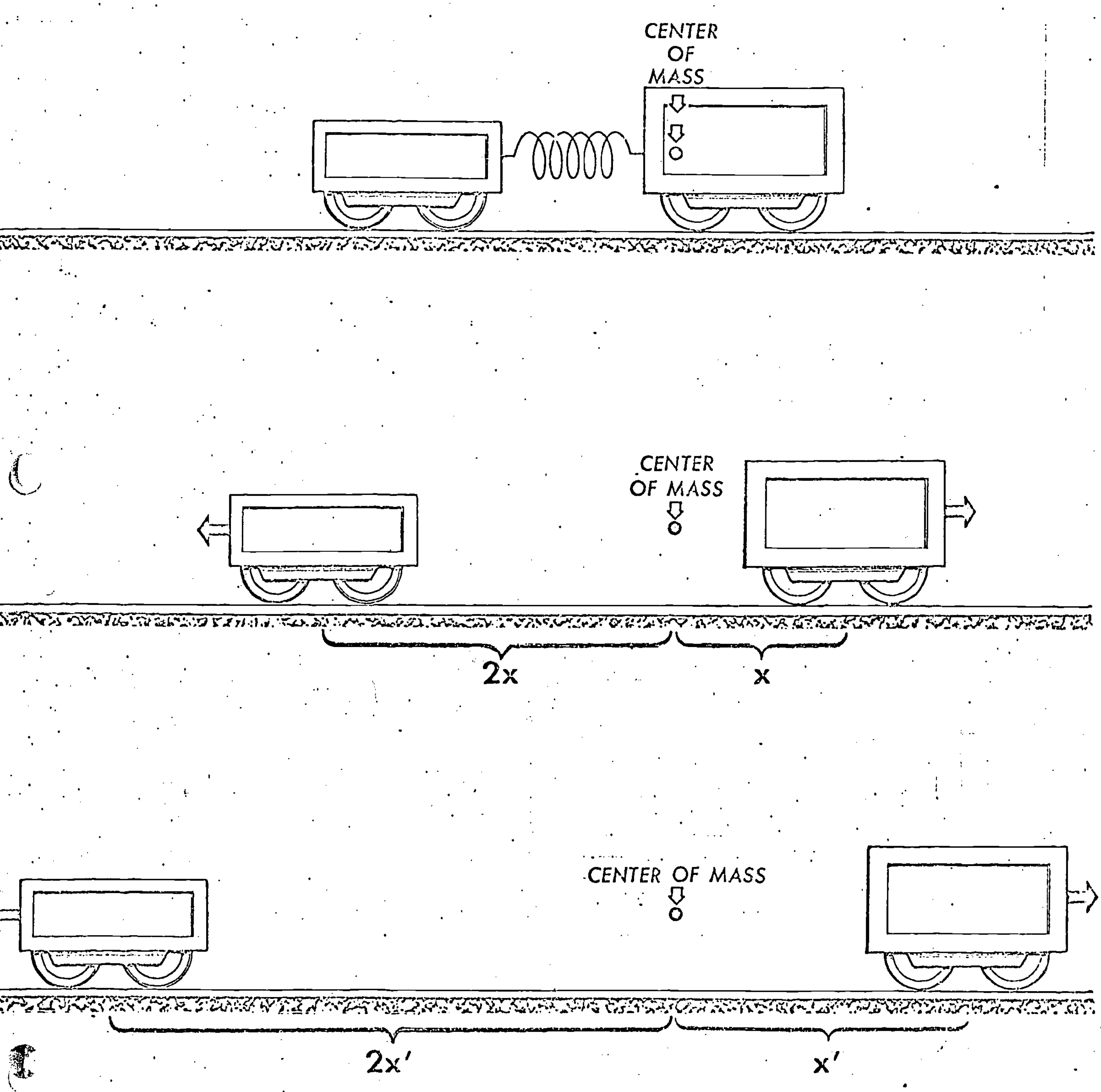


FIGURE 3

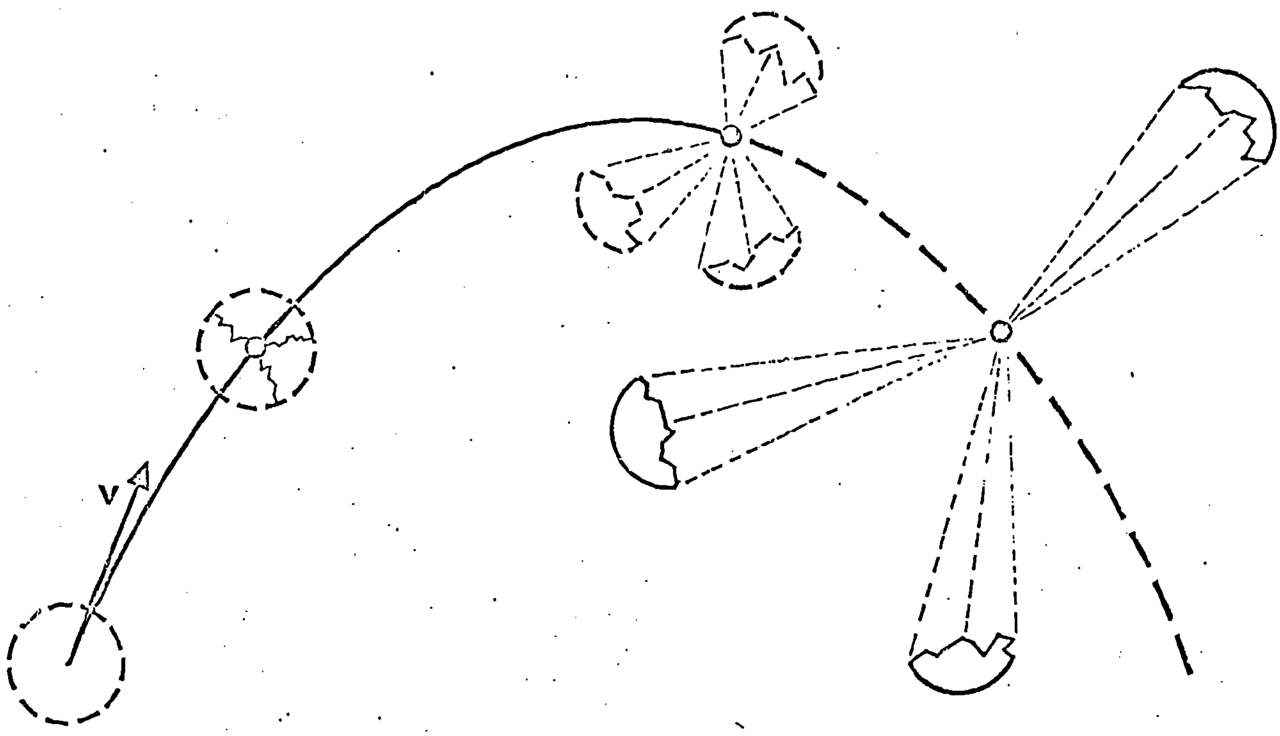


FIGURE 4

CONSERVATION OF MOMENTUM

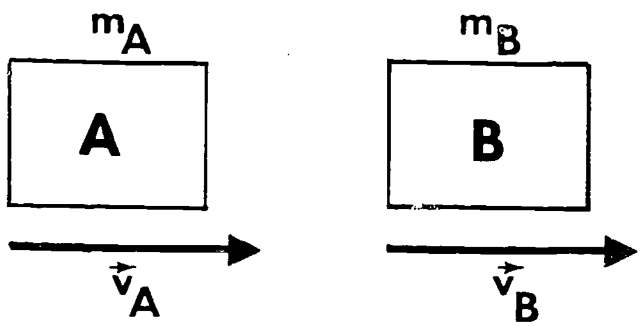


FIGURE 1

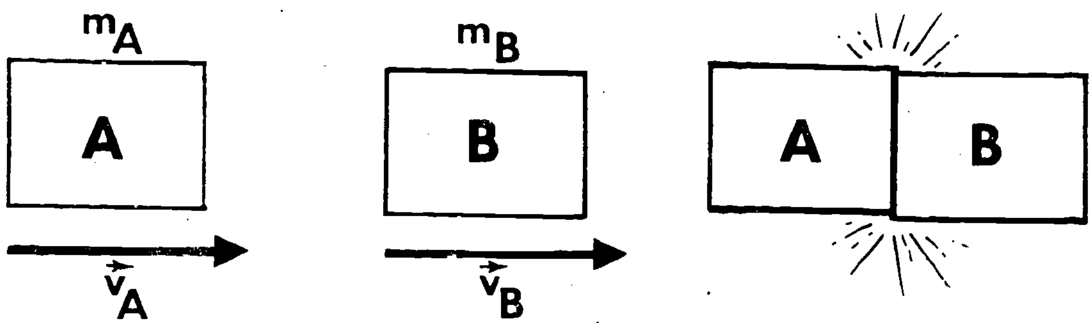


FIGURE 2

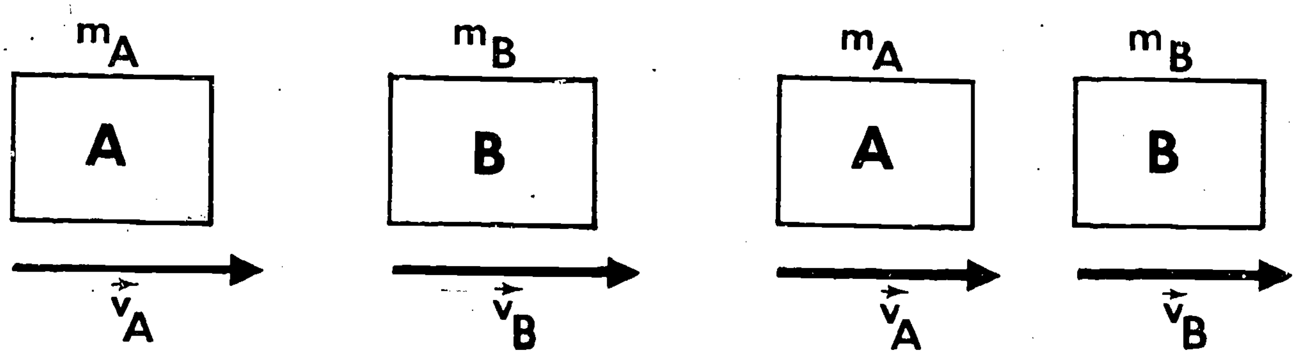


FIGURE 3

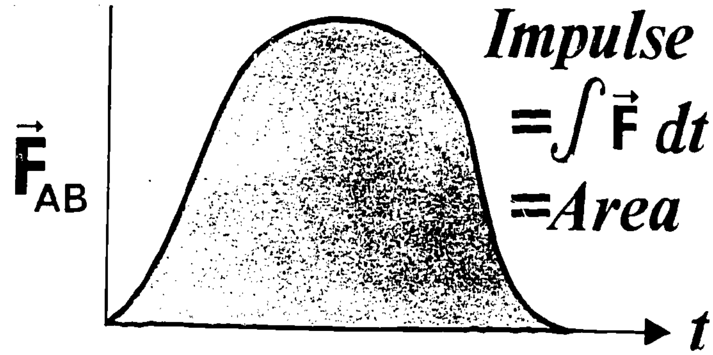


FIGURE (4)

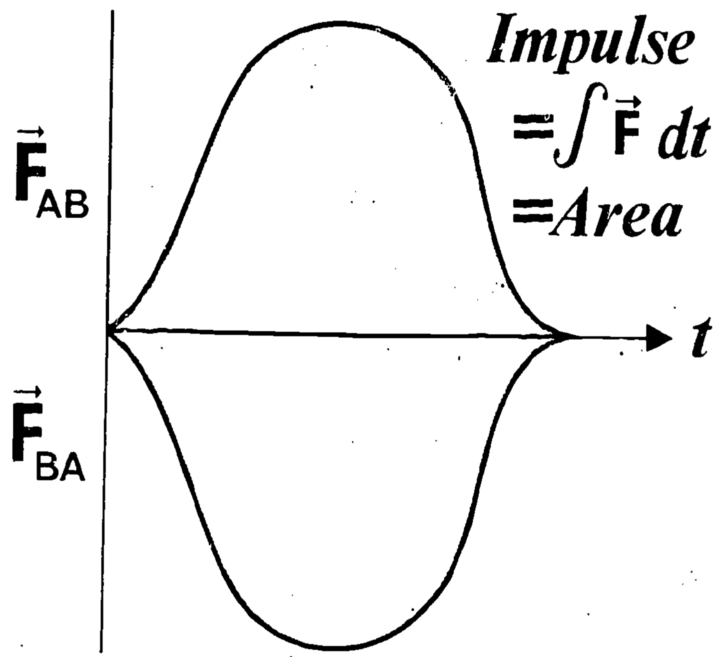


FIGURE (5)

Impulse applied to A = *−Impulse applied to B*

FIGURE (6)

Impulse applied to A = *−Impulse applied to B*

momentum change of A
= −momentum change of B

FIGURE 7

Impulse applied to A = *−Impulse applied to B*

momentum change of A
= −momentum change of B

No change in momentum

FIGURE 8

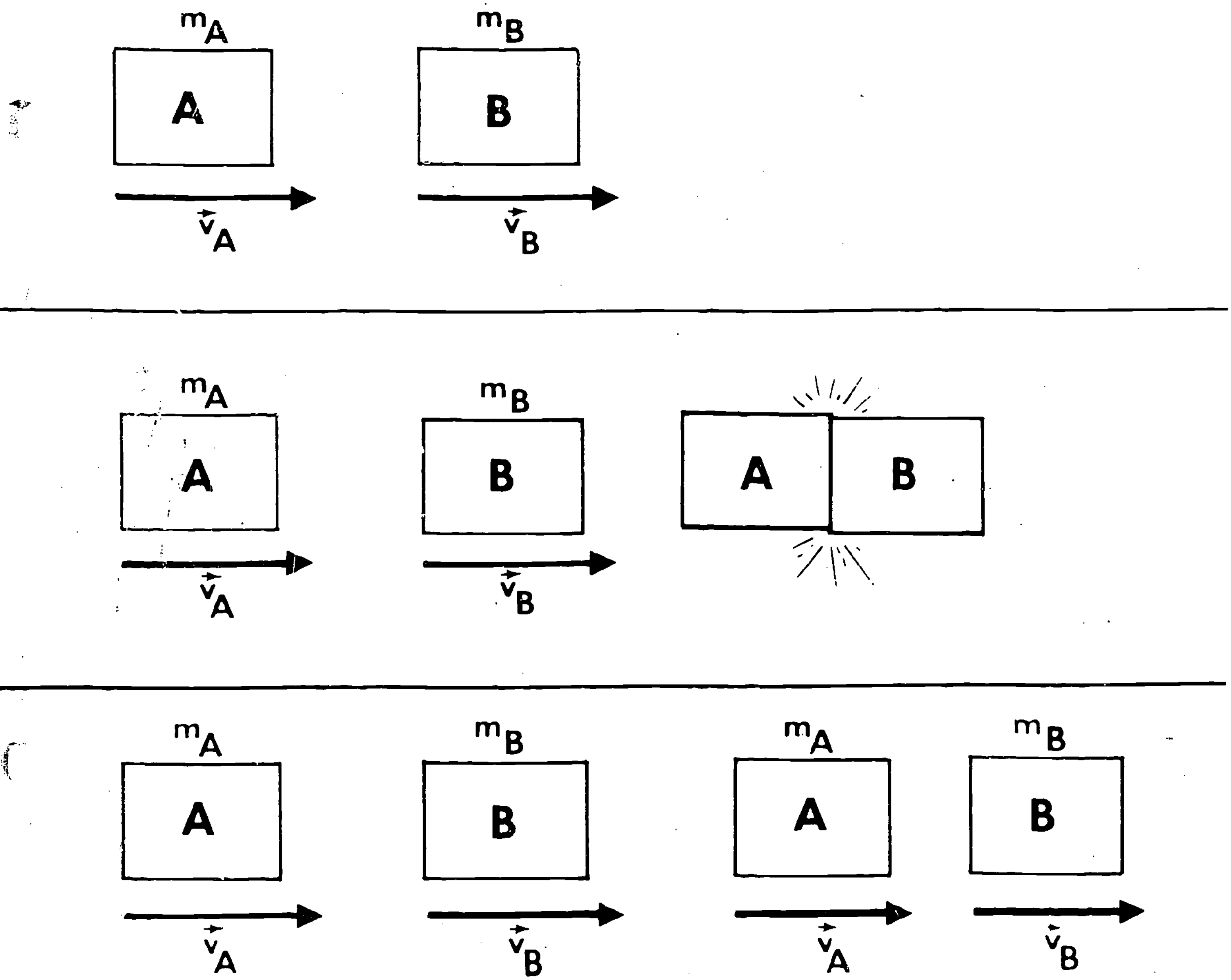


FIGURE 9

$$\underbrace{m_A \vec{v}_A + m_B \vec{v}_B}_{\text{MOMENTUM BEFORE COLLISION}} = \underbrace{m_A \vec{v}_{A'} + m_B \vec{v}_{B'}}_{\text{MOMENTUM AFTER COLLISION}}$$

FIGURE 10

CONSERVATION OF MOMENTUM

TERMINAL OBJECTIVES

6/2 B Solve momentum problems involving bodies with variable mass.

6/2 C Analyze situations and phenomena in which momentum is a significant factor.

Please turn to Page 21A of your STUDY GUIDE to continue with your work.

IMPULSE AND MOMENTUM

$$\vec{F} \cdot \vec{x} = \Delta KE$$

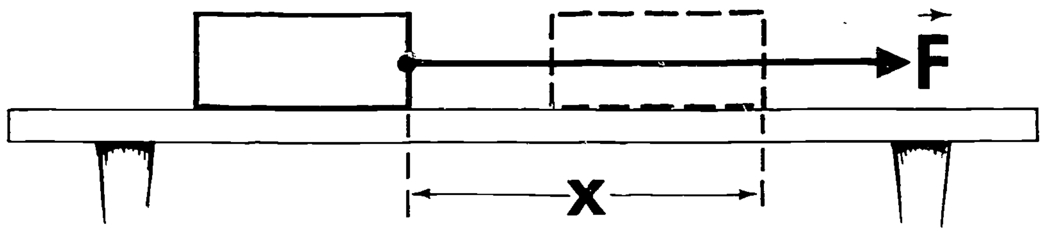


FIGURE 1

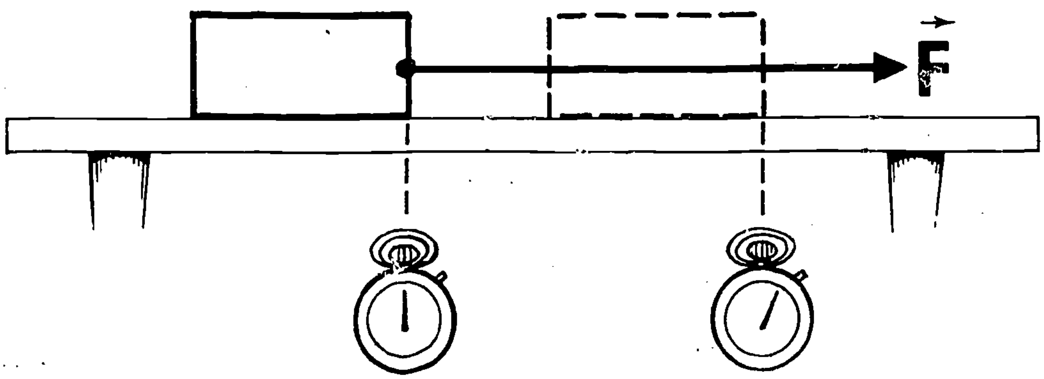


FIGURE 2

$$\vec{F} = m\vec{a}$$

$$\vec{F} = m \frac{d\vec{v}}{dt}$$

FIGURE 3

$$\vec{F} = m\vec{a}$$

$$\vec{F} = m \frac{d\vec{v}}{dt}$$

$$\vec{F}\,dt = m \frac{d\vec{v}}{\cancel{dt}} \cancel{dt} = m\,d\vec{v}$$

FIGURE 4

$$\vec{F} = m\vec{a}$$

$$\vec{F} = m \frac{d\vec{v}}{dt}$$

$$\vec{F}\,dt = m \frac{d\vec{v}}{\cancel{dt}} \cancel{dt} = m\,d\vec{v}$$

$$\vec{F}\,dt = m\,d\vec{v}$$

(vector equation)

FIGURE 5

$$\vec{F}\,dt = m\,d\vec{v}$$

$$\int_{t_1}^{t_2} \vec{F}\,dt = \int_{v_1}^{v_2} m\,d\vec{v}$$

FIGURE 6

$$\vec{F}\,dt = m\,d\vec{v}$$

$$\int_{t_1}^{t_2} \vec{F}\,dt = \int_{v_1}^{v_2} m\,d\vec{v}$$

$$\int_{t_1}^{t_2} \vec{F}\,dt = m\vec{v}_2 - m\vec{v}_1$$

FIGURE 7

$$\vec{F}\,dt = m\,d\vec{v}$$

$$\int_{t_1}^{t_2} \vec{F}\,dt = \int_{v_1}^{v_2} m\,d\vec{v}$$

$$\int_{t_1}^{t_2} \vec{F}\,dt = m\vec{v}_2 - m\vec{v}_1$$

Impulse = *change in momentum*

FIGURE 8

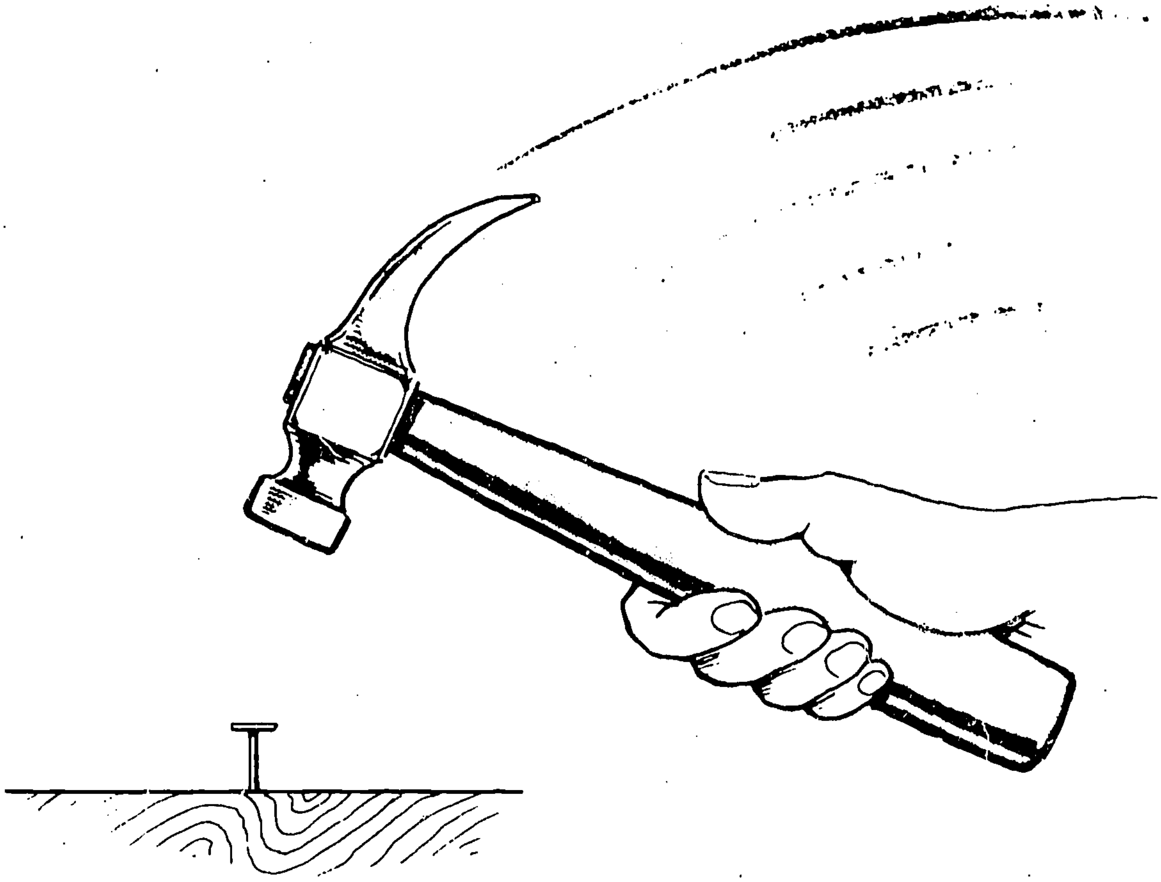


FIGURE 9

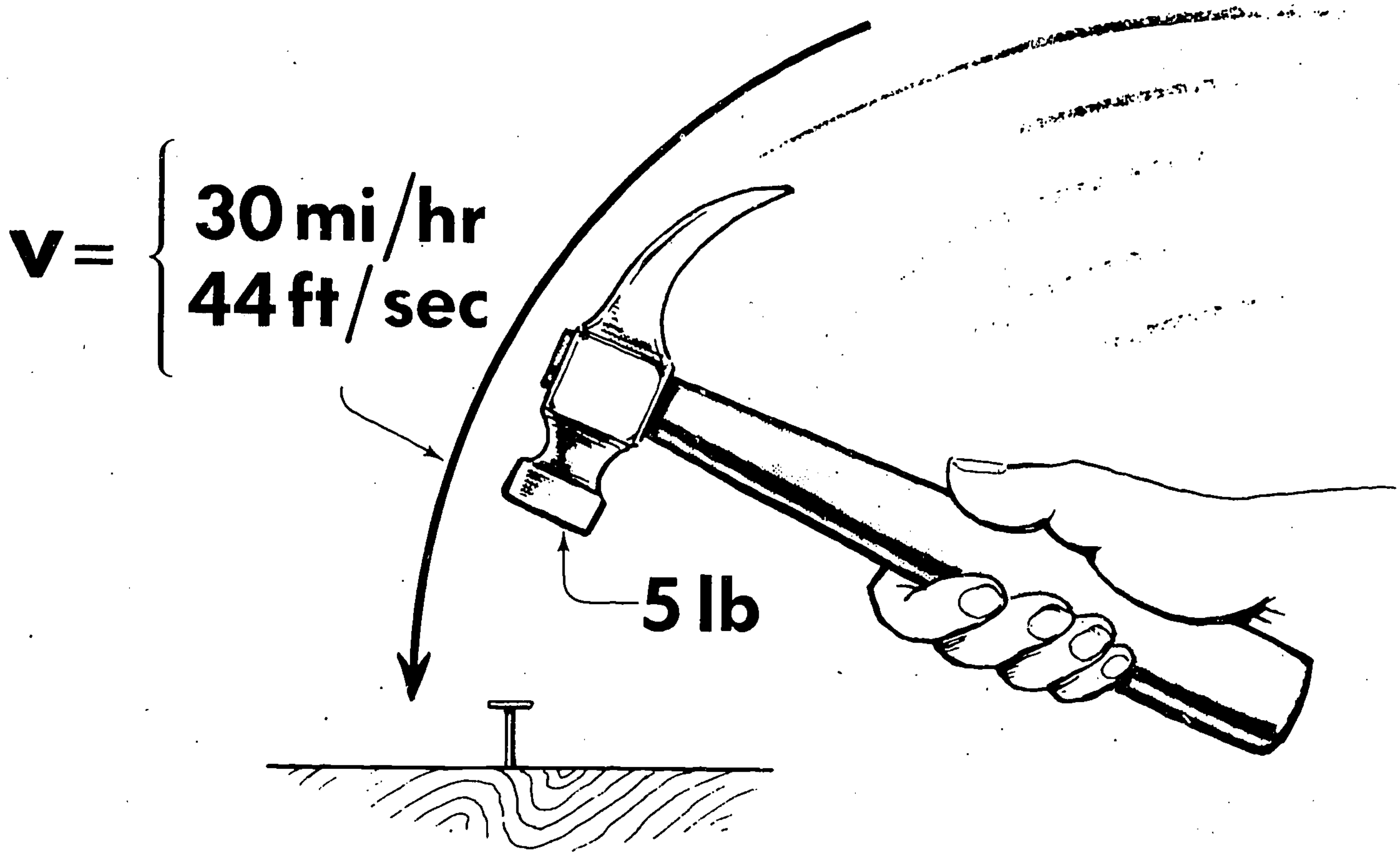


FIGURE 10

$$\text{Impulse} = \text{change in momentum}$$

$$\text{Mass} = \frac{5}{32}\ \text{slug}$$

$$v_1 = 44\ ft/sec$$

$$v_2 = 0\ ft/sec$$

FIGURE 11

$$\text{change in momentum} = \frac{5}{32} \times 44 - 0\ \frac{\text{slug ft}}{\text{sec}}$$

FIGURE 12

$$\text{change in momentum} = \frac{5}{32} \times 44 - 0\ \frac{\text{slug ft}}{\text{sec}}$$

$$\text{impulse} = \overline{F}t \qquad \overline{F} = \text{average force}$$

$$= \overline{F}\,\frac{1}{100}$$

FIGURE 13

$$\bar{F} \times \frac{1}{100} = \frac{5}{32} \times 44$$

$$\bar{F} = \left(100 \times \frac{5}{32} \times 44\right) \text{ lbs}$$

$$= 687 \text{ lbs or } \frac{1}{3} \text{ ton (APPROX)}$$

FIGURE 14

IMPULSE AND MOMENTUM

TERMINAL OBJECTIVES

6/2 A Solve momentum problems involving bodies with constant mass.

6/3 A Analyze situations which involve net impulsive forces acting on bodies of constant mass.

Please turn to page 31A of your STUDY GUIDE to continue with your work.

COLLISIONS

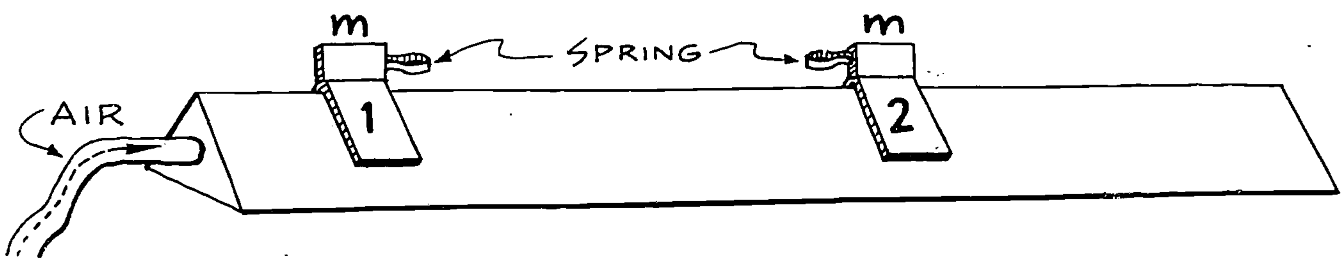


FIGURE 1

$m = m =$ mass of each glider

u_1 = velocity of glider 1 BEFORE collision

u_2 = velocity of glider 2 BEFORE collision = 0

v_1 = velocity of glider 1 AFTER collision

v_2 = velocity of glider 2 AFTER collision

FIGURE 2

Before collision the system momentum = mu_1

After the collision, the system momentum = $mv_1 + mv_2$

FIGURE 3

$mu_1 = mv_1 + mv_2$ and dividing by m

$u_1 = v_1 + v_2$

FIGURE 4

$$\frac{1}{2} mu_1^2 = \frac{1}{2} mv_1^2 + \frac{1}{2} mv_2^2$$

$$u_1^2 = v_1^2 + v_2^2$$

FIGURE 5

$$u_1 = v_1 + v_2$$

$$u_1^2 = v_1^2 + v_2^2$$

FIGURE 6

$u_1^2 = v_1^2 + 2v_1v_2 + v_2^2$ (linear equation squared)

$u_1^2 = v_1^2 + v_2^2$

Subtracting

$0 = 2v_1 v_2$

so $v_1 = 0$ or $v_2 = 0$ or both v_1 <u>and</u> $v_2 = 0$

FIGURE 7

$$\text{IF } v_1 = 0_1 \text{ then}$$
$$u_1 = 0 + v_2$$
$$u_1 = v_2$$

FIGURE 8

$$\text{IF } v_2 = 0, \text{ then}$$
$$u_1 = v_1 + 0$$
$$u_1 = v_1$$

FIGURE 9

COLLISIONS

TERMINAL OBJECTIVES

7/1 A Analyze a two-body collision problem in terms of the impulse mentum theorem.

7/1 C Apply the principle of conservation of momentum to the solution of problems involving inelastic collision.

GRAVITATION

"Every object in the universe attracts every other object with a force that is directly proportional to the product of their masses and inversely proportional to the square of the distance between their centers"

$$F = G\frac{m_1 m_2}{r^2}$$

FIGURE 1

(a) $F \propto ma$

(b) $F = kma$

(c) $F = ma$ since $k = 1$ if m is
in kilograms, a is
in m/sec and F is
in newtons.

FIGURE 2

$$G = \frac{m_1 m_2}{Fr^2}$$

FIGURE 3

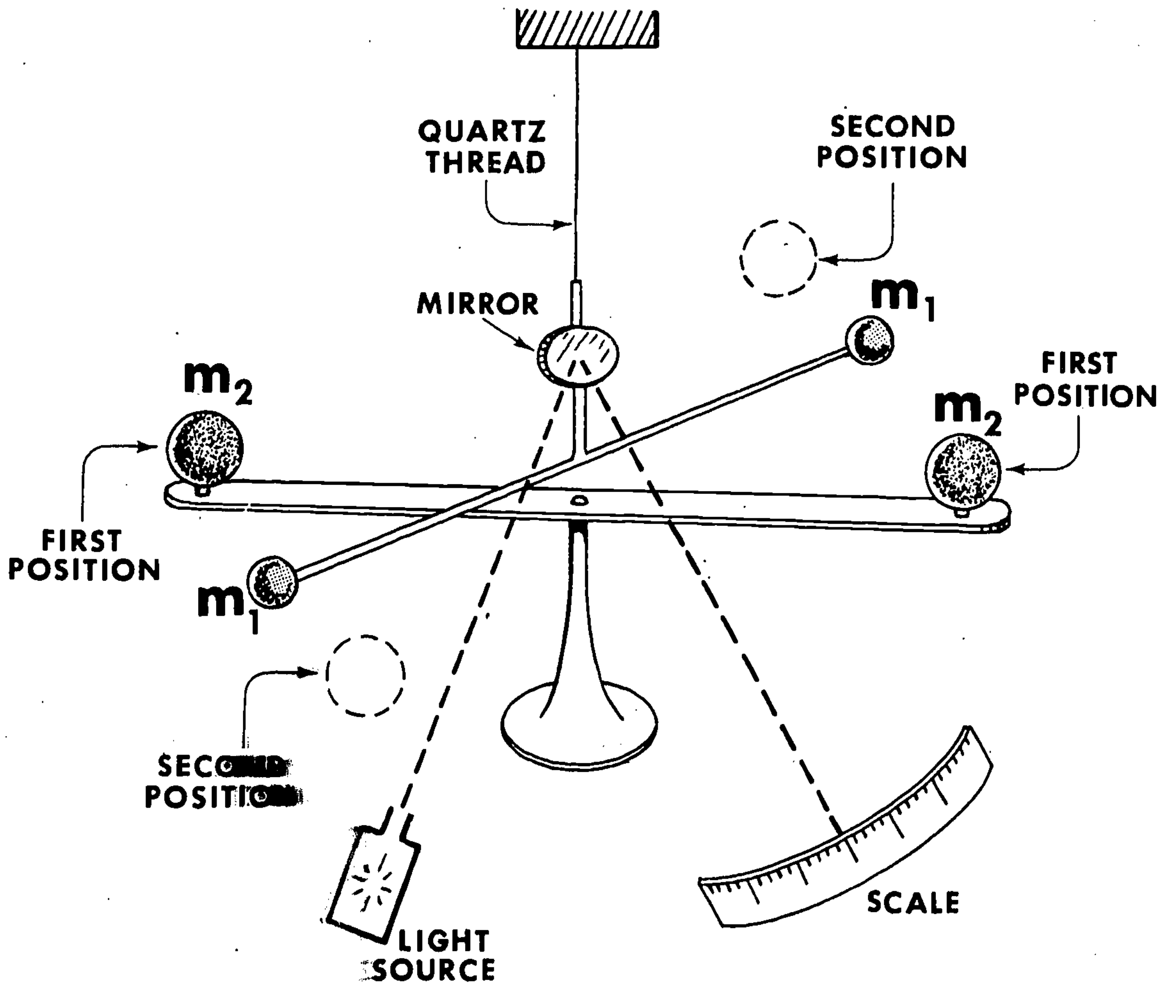

QUARTZ
THREAD
SECOND
POSITION
MIRROR
m_1
m_2
FIRST
POSITION
m_2
FIRST
POSITION
m_1
LIGHT
SOURCE
SCALE

FIGURE 4

$$G = \frac{k \ \theta \ r^2}{m_1 \, m_2 \, L}$$

where: k = torsional constant of suspension thread

θ = angle of twist

r = distance from center of m_1 to center of m_2

L = length of horizontal bar

FIGURE 5

$$G = \frac{k \ \theta \ r^2}{m_1 \, m_2 \, L}$$

$$G = \frac{\frac{kg \cdot m^2}{sec^2} \cdot radians \cdot m^2}{kg \cdot kg \cdot m}$$

$$G = \frac{nt \cdot m^2}{kg^2}$$

FIGURE 6

GRAVITATION

TERMINAL OBJECTIVES

8/1 A Analyze gravitational force actions between two particles in terms of the gravitational field.

CALCULATION OF $\vec{E}$ FOR AN INFINITE UNIFORMLY CHARGED WIRE

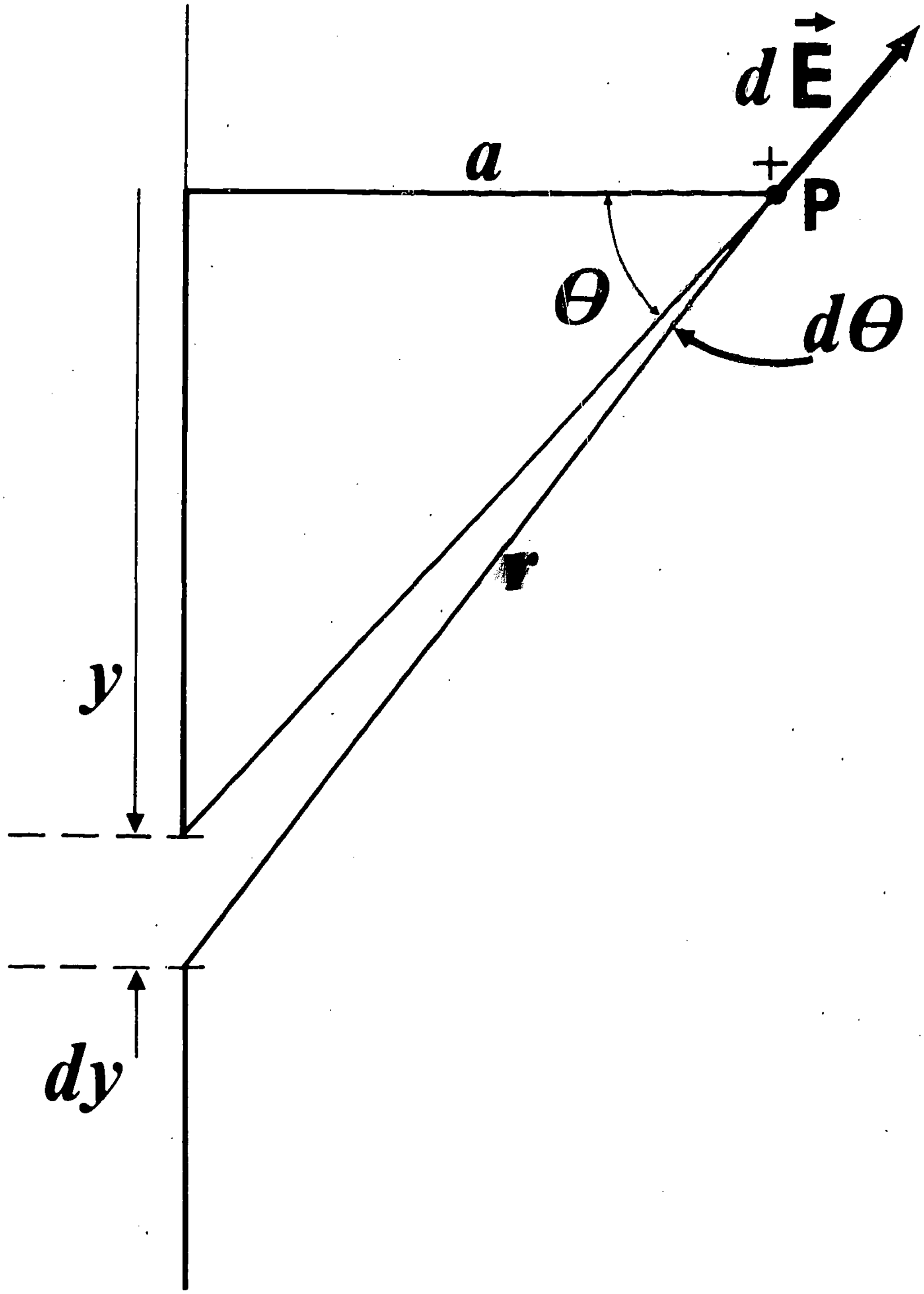
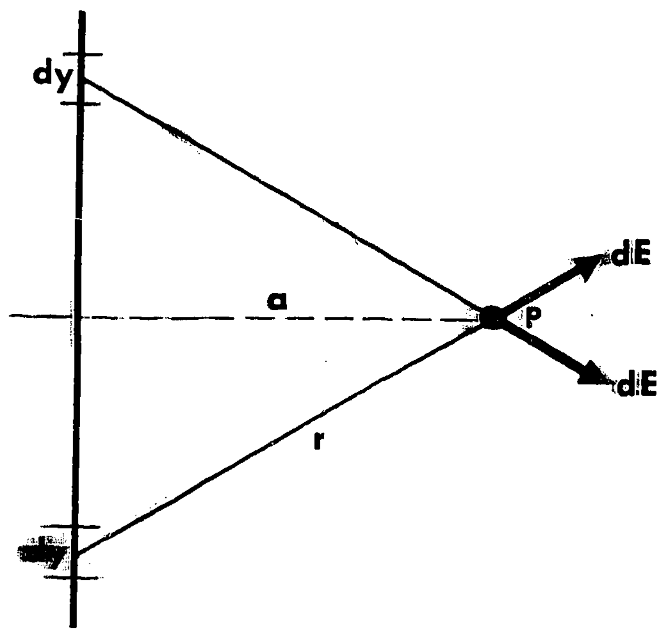


FIGURE 1

$$d\vec{E} = \frac{1}{4\pi\epsilon_0} \frac{\lambda\, dy}{r^2} \hat{r}$$

FIGURE 2



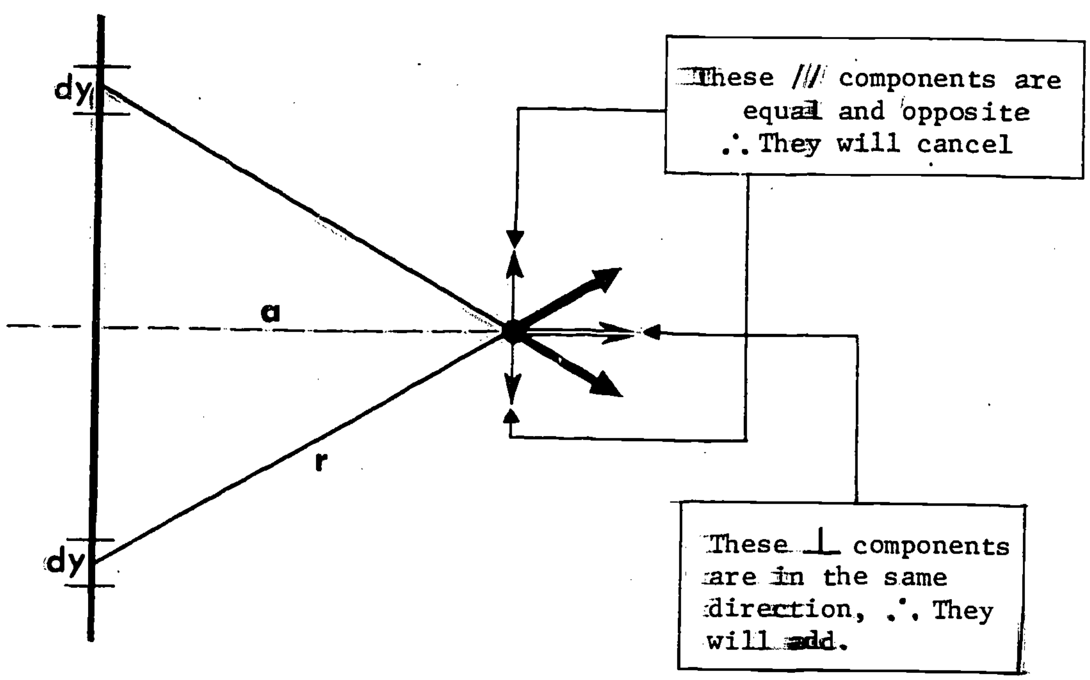
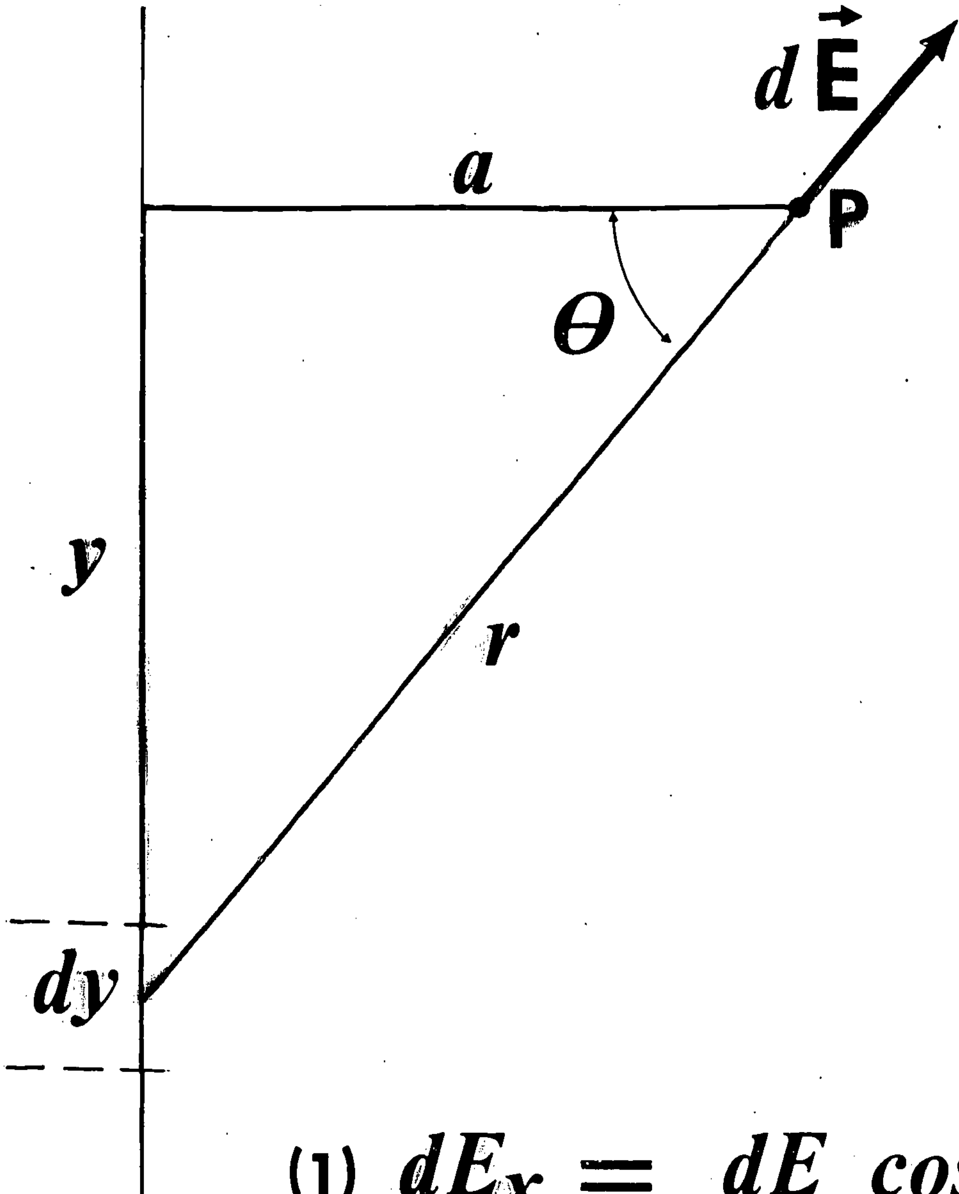


FIGURE 3

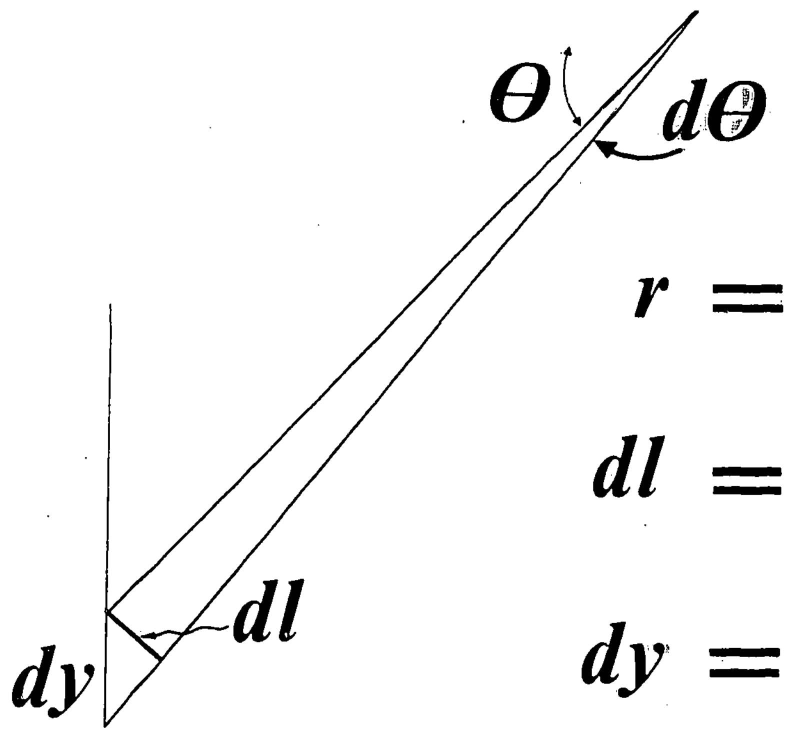


$$(1)\quad dE_x = dE \cos\theta$$

$$(2)\quad d\vec{E} = \frac{1}{4\pi\epsilon_0}\,\frac{\lambda\,dy}{r^2}\,\hat{r}$$

$$(3)\quad dE_x = \frac{1}{4\pi\epsilon_0}\,\frac{\lambda\,dy}{r^2}\cos\theta$$

FIGURE 4



$$r = \frac{a}{\cos\theta}$$

$$dl = r\,d\theta$$

$$dy = \frac{r\,d\theta}{\cos\theta}$$

FIGURE 5

$$dE_x = \frac{1}{4\pi\epsilon_0}\,\frac{\lambda \cancel{\cos\theta}}{\cancel{r^2}}\,\frac{\cancel{r}\,d\theta}{\cancel{\cos\theta}}$$

$$= \frac{1}{4\pi\epsilon_0}\,\frac{\lambda \cos\theta\, d\theta}{a}$$

$$E_x = \frac{1}{4\pi\epsilon_0}\,\frac{\lambda}{a}\int_{\theta_1}^{\theta_2}\cos\theta\, d\theta$$

$$= \frac{1}{4\pi\epsilon_0}\,\frac{\lambda}{a}\left[\sin\theta_2 - \sin\theta_1\right]$$

For a infinitely long wire: $\theta_2 = 90°$

$\theta_1 = -90°$

$$E_x = \frac{1}{2\pi\epsilon_0}\,\frac{\lambda}{a}$$

FIGURE 6

CALCULATION OF $\vec{E}$ FOR AN INFINITE UNIFORMLY CHARGED WIRE

TERMINAL OBJECTIVES

10/2 B Answer questions and solve problems relating to atomic models based on sperically symmetric charge distributions.

11/1 A Solve problems and answer questions on the relationship between potential and field intensity.

DEFLECTION OF ELECTRONS IN AN ELECTRIC FIELD

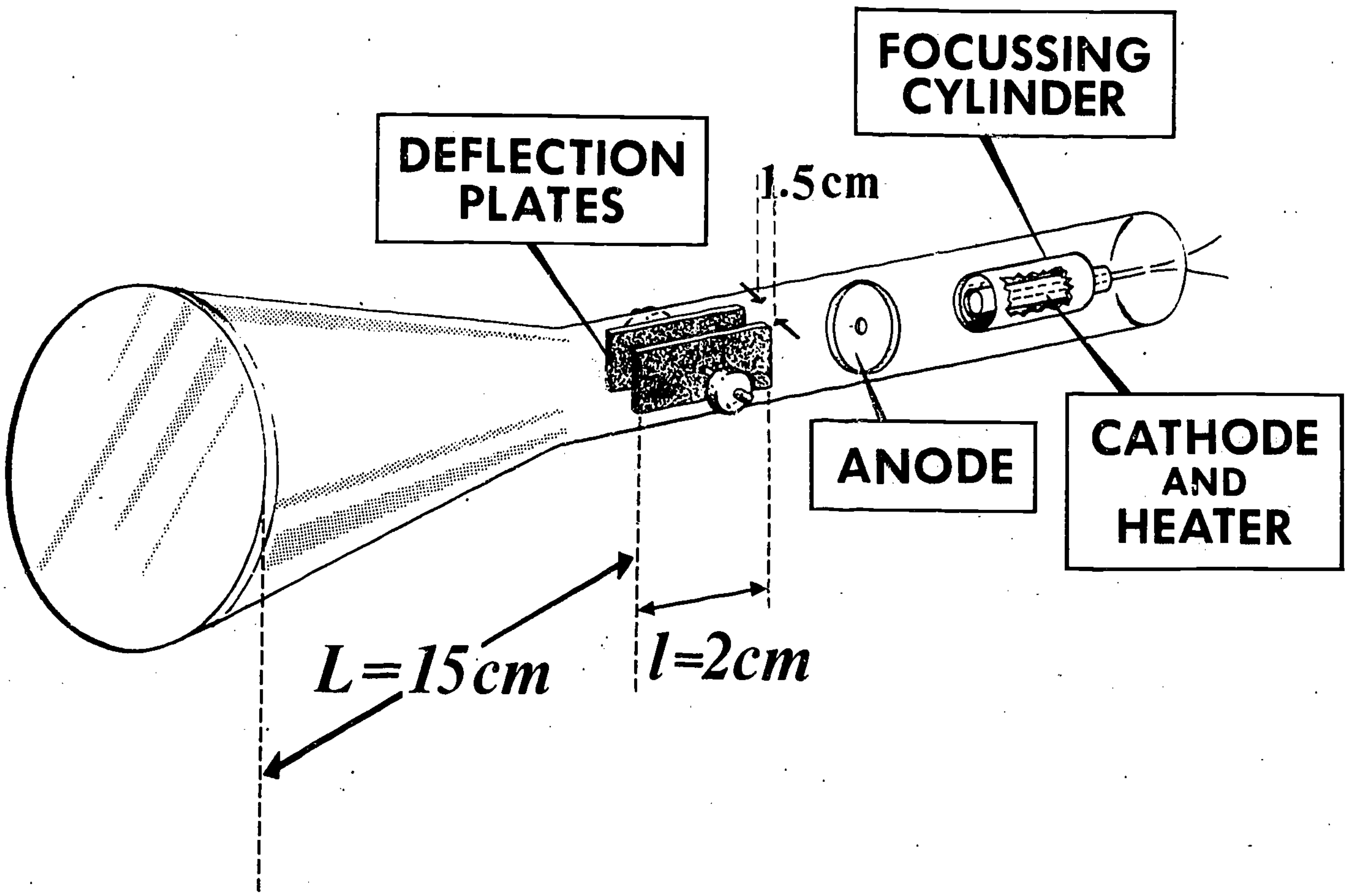

FOCUSSING CYLINDER
DEFLECTION PLATES
1.5cm
ANODE
CATHODE AND HEATER
L=15cm
l=2cm

FIGURE 1

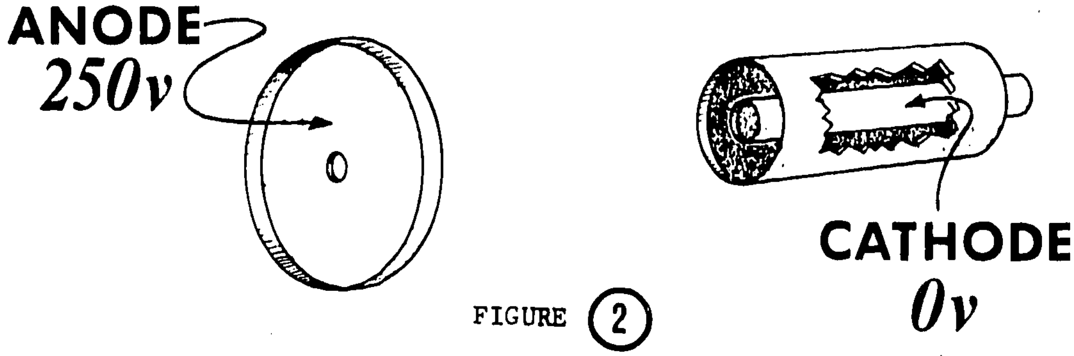
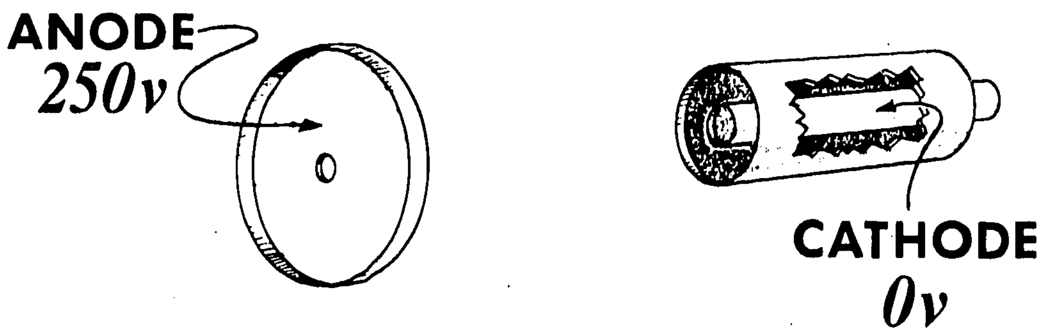
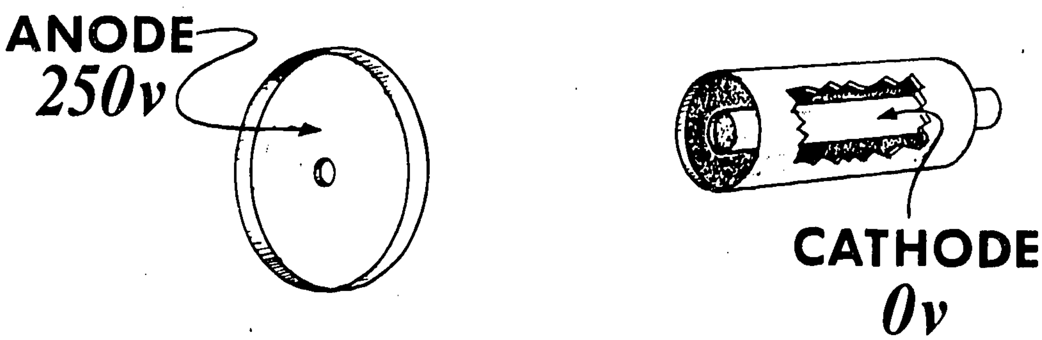


FIGURE 2



Loss in Potential Energy = *Gain in Kinetic Energy*

FIGURE 3



Loss in Potential Energy = *Gain in Kinetic Energy*

$$eV = \frac{1}{2} m v_h^2$$

$$v_h = \sqrt{\frac{2eV}{m}}$$

FIGURE 4

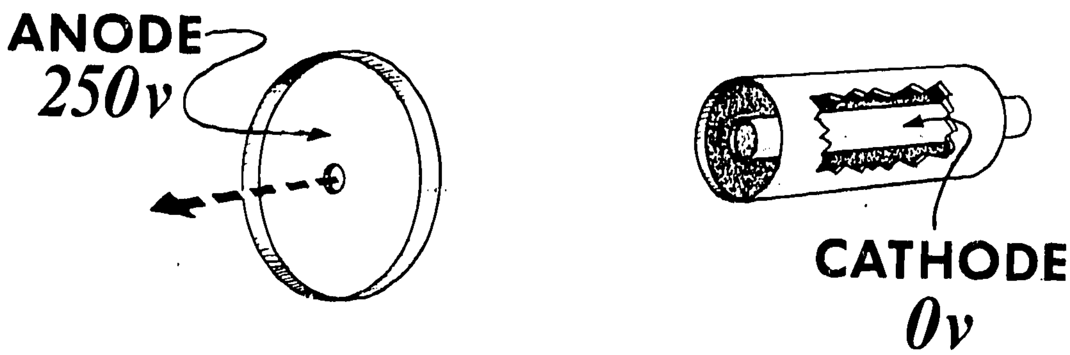


FIGURE 5

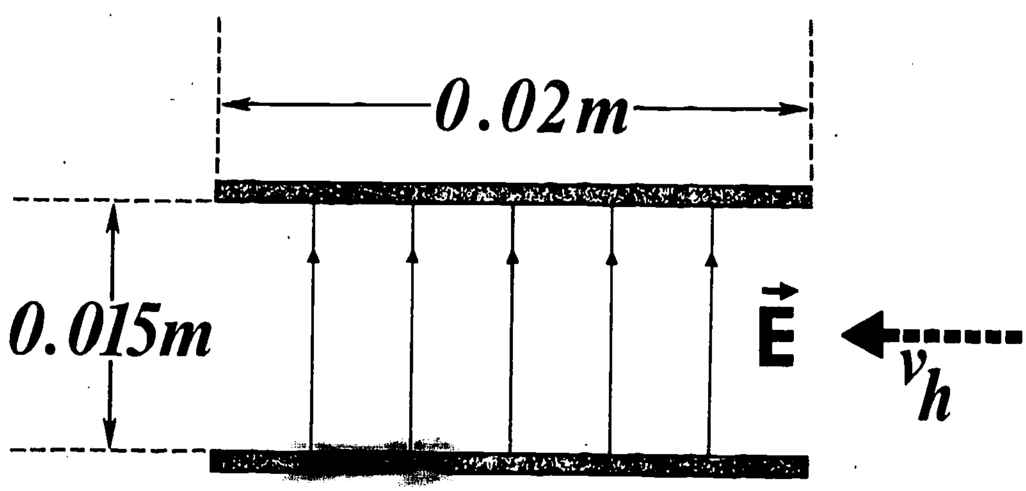
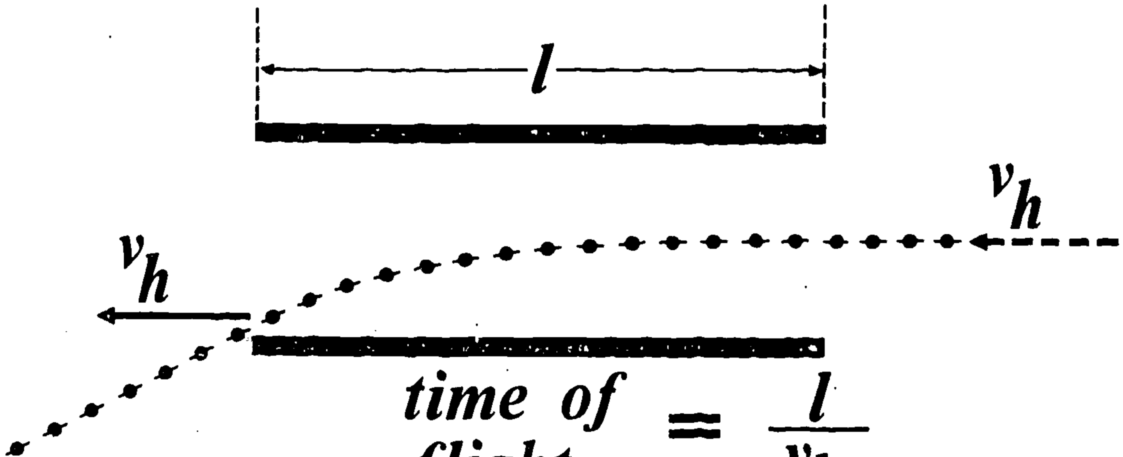
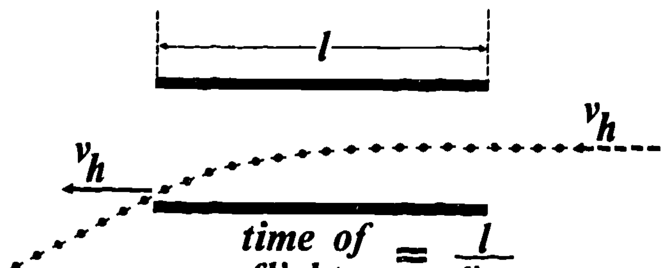


FIGURE 6



$$\text{time of flight} = \frac{l}{v_h}$$

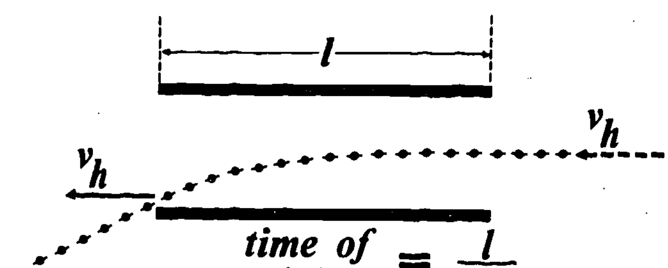
FIGURE 7



$$\text{time of flight} = \frac{l}{v_h}$$

$$\text{force on electrons} = Ee$$

FIGURE 8

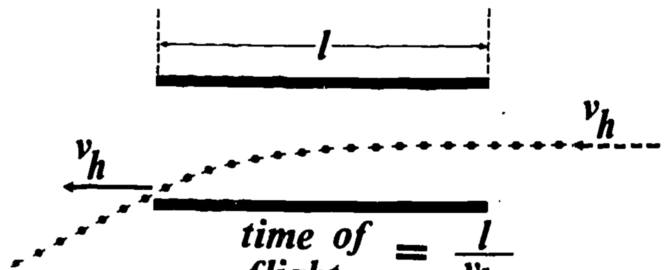


$$\text{time of flight} = \frac{l}{v_h}$$

$$\text{force on electrons} = Ee$$

$$\text{acceleration} = \frac{F}{m} = \frac{Ee}{m}$$

FIGURE 9



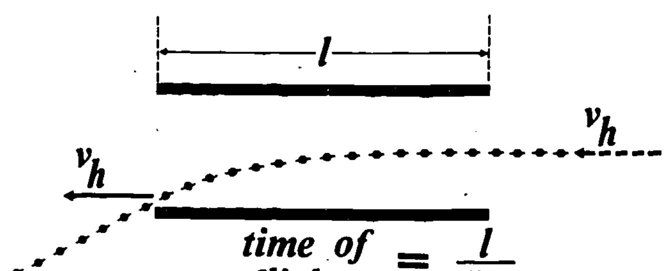
$$\text{time of flight} = \frac{l}{v_h}$$

$$\text{force on electrons} = Ee$$

$$\text{acceleration} = \frac{F}{m} = \frac{Ee}{m}$$

$$\textbf{deflection in plate region} = \frac{1}{2}at^2 = \frac{1}{2}\frac{Ee}{m}\left(\frac{l}{v_h}\right)^2$$

FIGURE 10



$$\text{time of flight} = \frac{l}{v_h}$$

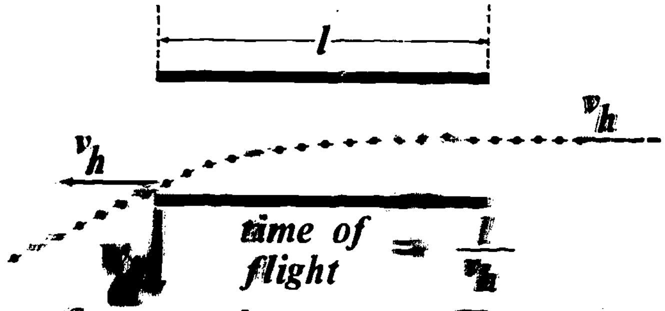
$$\text{force on electrons} = Ee$$

$$\text{acceleration} = \frac{F}{m} = \frac{Ee}{m}$$

$$\text{deflection in plate region} = \frac{1}{2}at^2 = \frac{1}{2}\frac{Ee}{m}\left(\frac{l}{v_h}\right)^2$$

$$\textbf{deflection acceleration} = \frac{Ee}{m}$$

FIGURE 11



time of flight $= \dfrac{l}{v_h}$

force on electrons $= Ee$

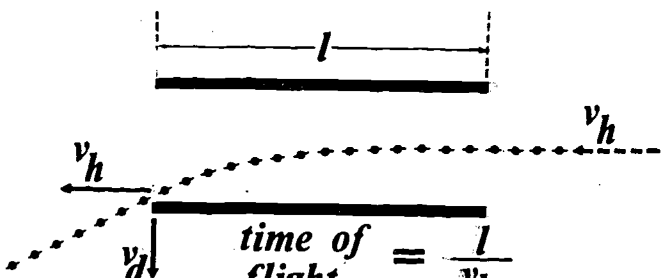
acceleration $= \dfrac{F}{m} = \dfrac{Ee}{m}$

deflection in plate region $= \dfrac{1}{2}at^2 = \dfrac{1}{2}\dfrac{Ee}{m}\left(\dfrac{l}{v_h}\right)^2$

deflection acceleration $= \dfrac{Ee}{m}$

$\therefore$ **final deflected velocity** $= \dfrac{l}{v_h}\dfrac{Ee}{m}$

FIGURE 12



time of flight $= \dfrac{l}{v_h}$

force on electrons $= Ee$

acceleration $= \dfrac{F}{m} = \dfrac{Ee}{m}$

deflection in plate region $= \dfrac{1}{2}at^2 = \dfrac{1}{2}\dfrac{Ee}{m}\left(\dfrac{l}{v_h}\right)^2$

deflection acceleration $= \dfrac{Ee}{m}$

$\therefore$ final deflected velocity $= \dfrac{l}{v_h}\dfrac{Ee}{m}$

additional deflection $=$ **drift time** $\times v_d$

$$= \frac{L}{v_h} v_d$$

FIGURE 13

$$\text{deflection in plate region} = \frac{1}{2}at^2 = \frac{1}{2}\frac{Ee}{m}\left(\frac{l}{v_h}\right)^2$$

$$\text{additional deflection} = \text{drift time} \times v_d$$

$$= \frac{L}{v_h} v_d$$

$$\text{total deflection} = \text{sum of these} = \frac{Ee}{m}\frac{l}{v_h^2}\left(\frac{l}{2} + L\right)$$

$$= 4.2 \times 10^{-2} m$$

FIGURE 14

DEFLECTION OF ELECTRONS IN AN ELECTRIC FIELD

TERMINAL OBJECTIVES

10/3 B Answer questions and solve problems relating to potential and field strength.

FLUX

FIGURE

FIGURE

V
V

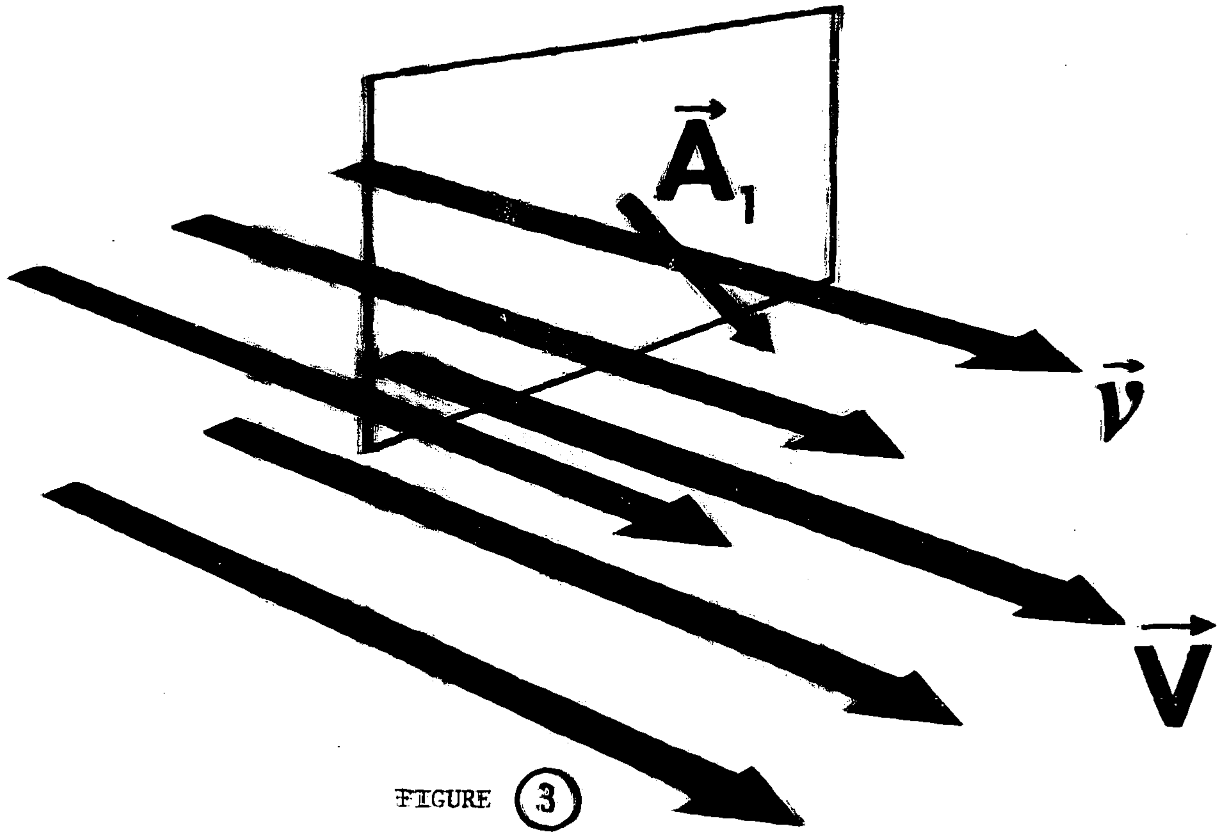


FIGURE 3

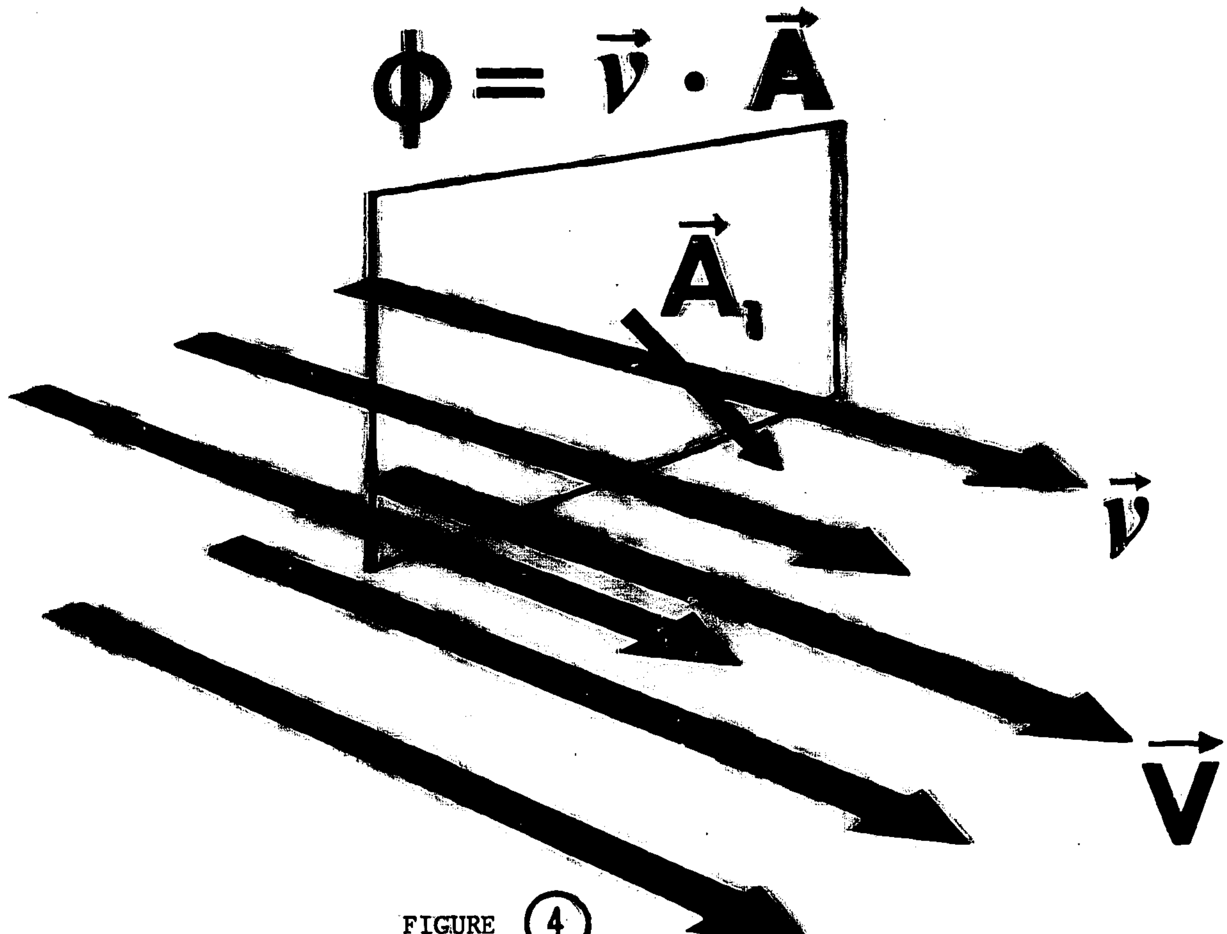


FIGURE 4

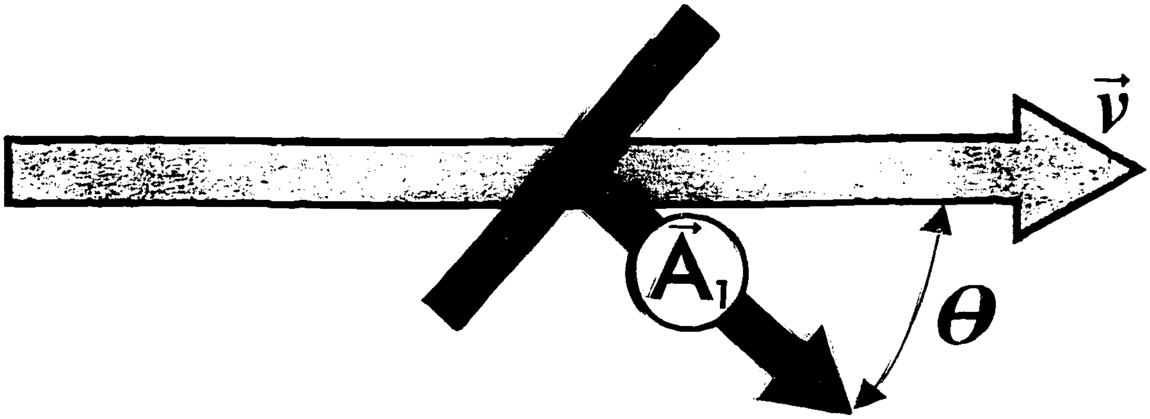


FIGURE (5)

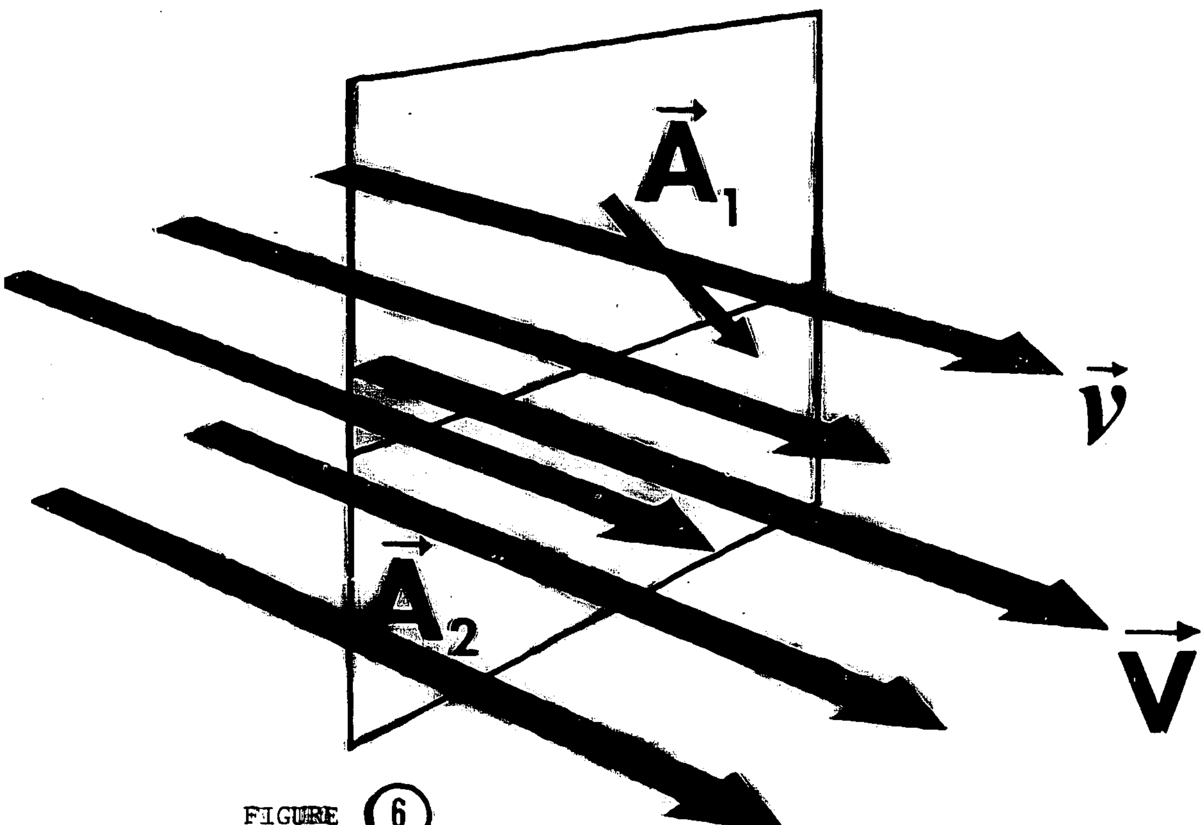


FIGURE (6)

$$\phi = \vec{v} \cdot \vec{A}_1 + \vec{V} \cdot \vec{A}_2$$

FIGURE (7)

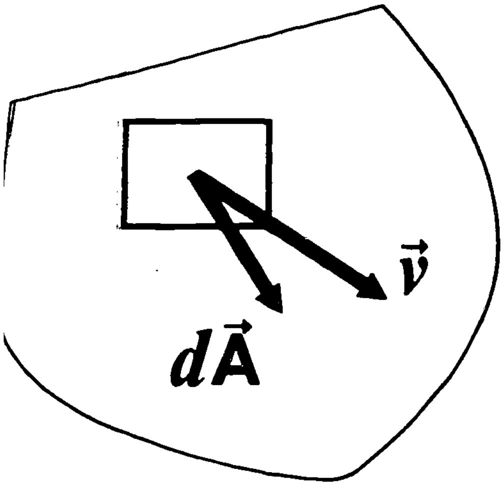


FIGURE 8

$$\phi = \sum \vec{v} \cdot d\vec{A}$$

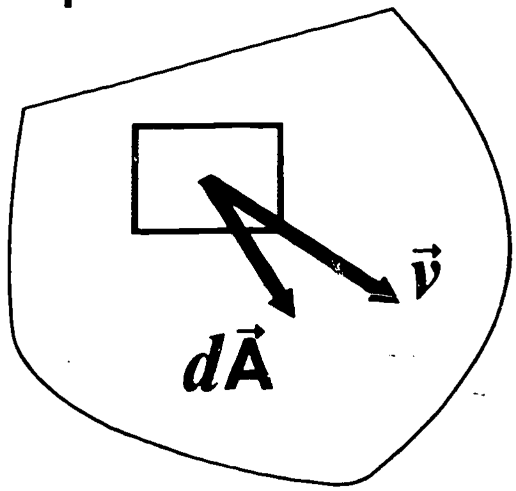


FIGURE 9

$$\phi = \int \vec{v} \cdot d\vec{A}$$

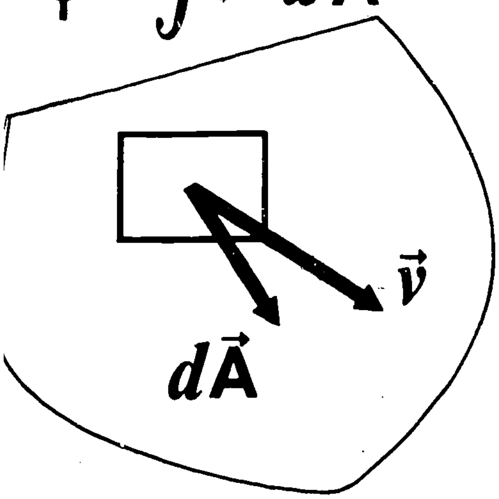


FIGURE 10

$$\phi = \int \vec{E} \cdot d\vec{A}$$

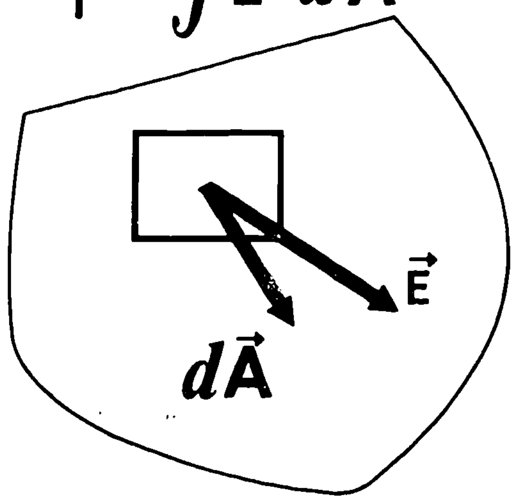


FIGURE 11

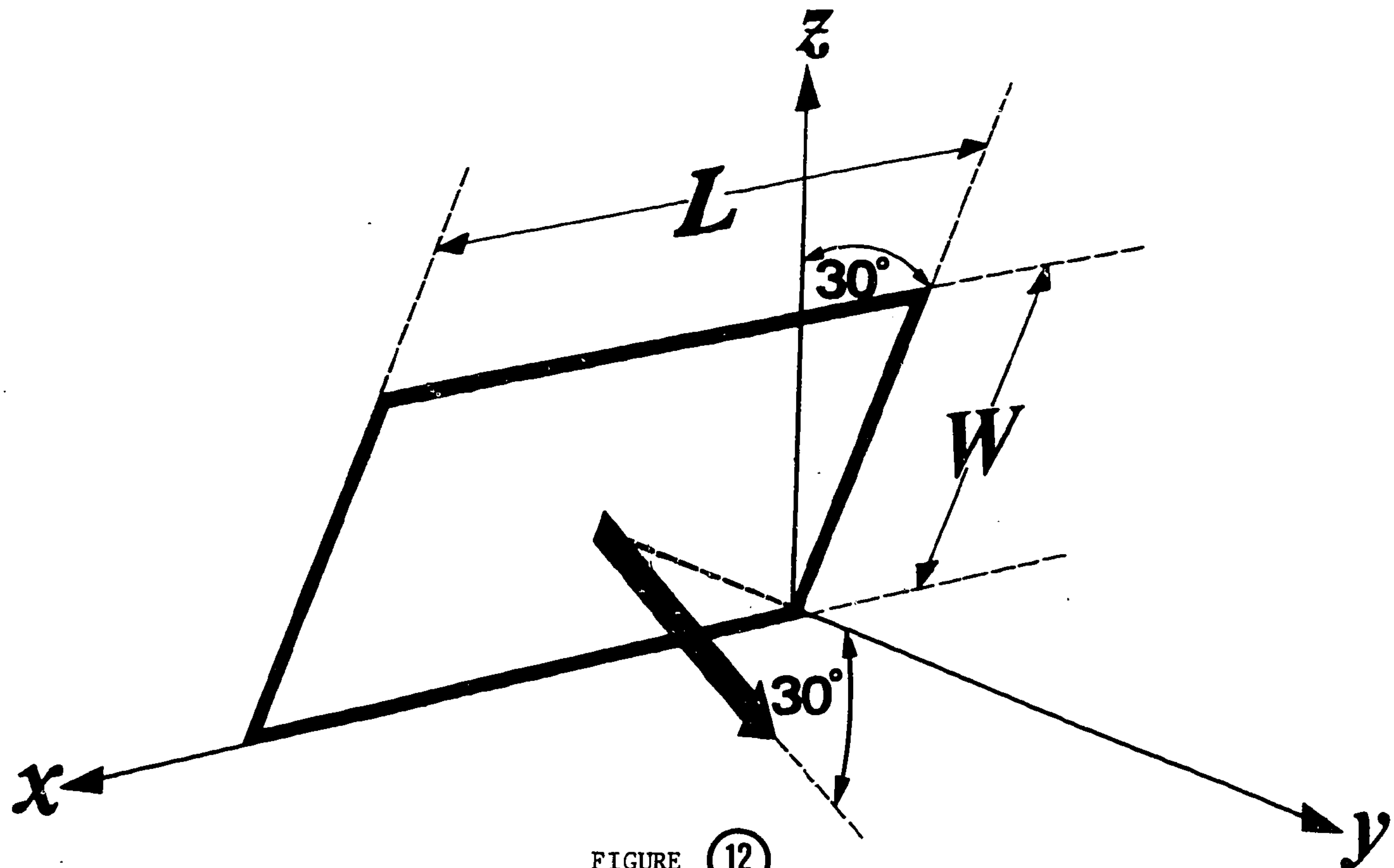


FIGURE (12)

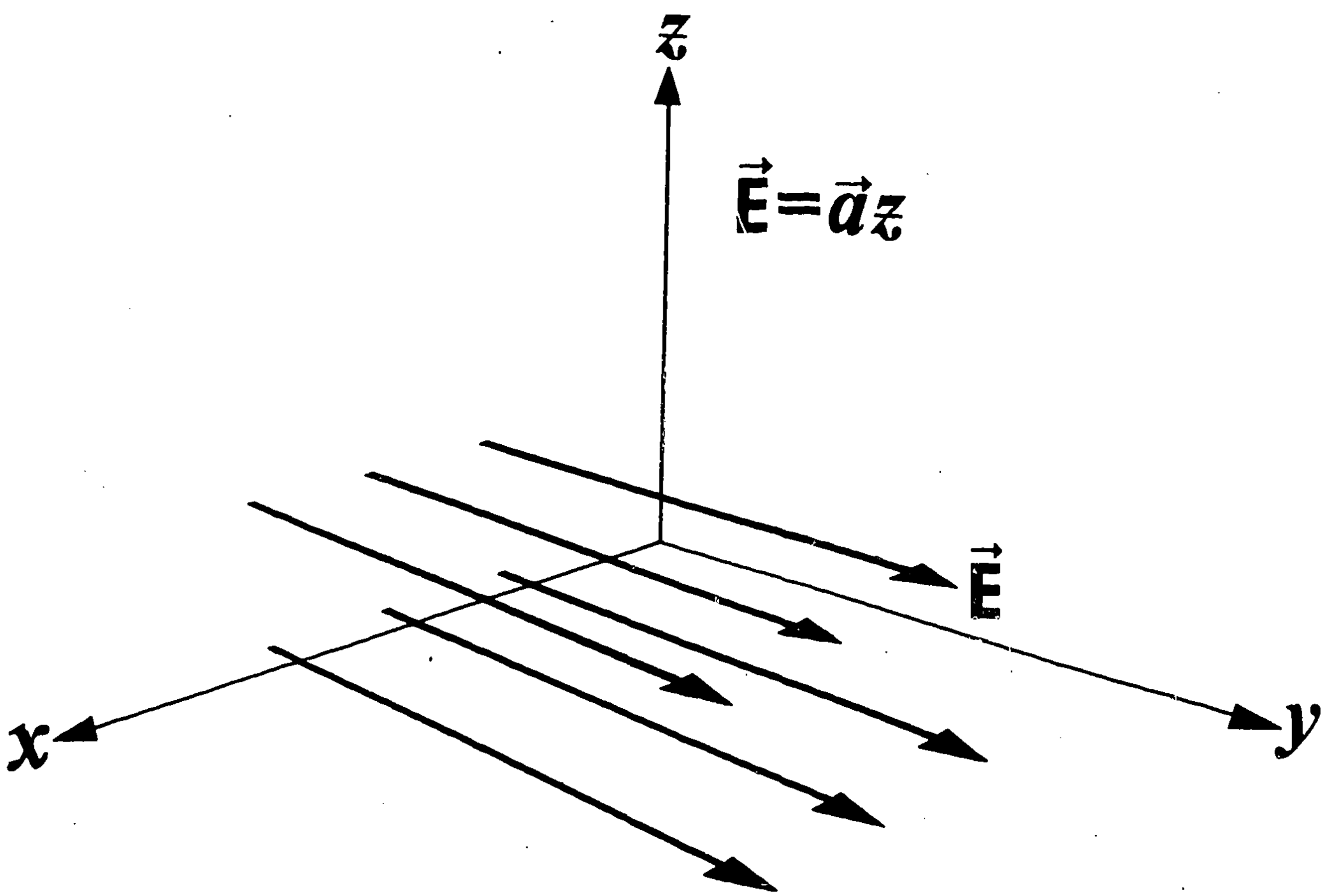


FIGURE (13)

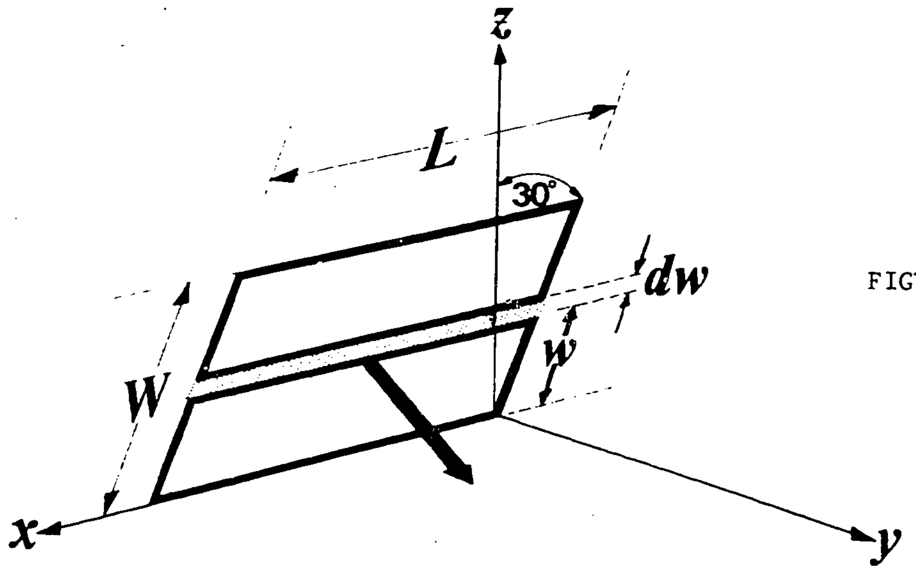


FIGURE (14)

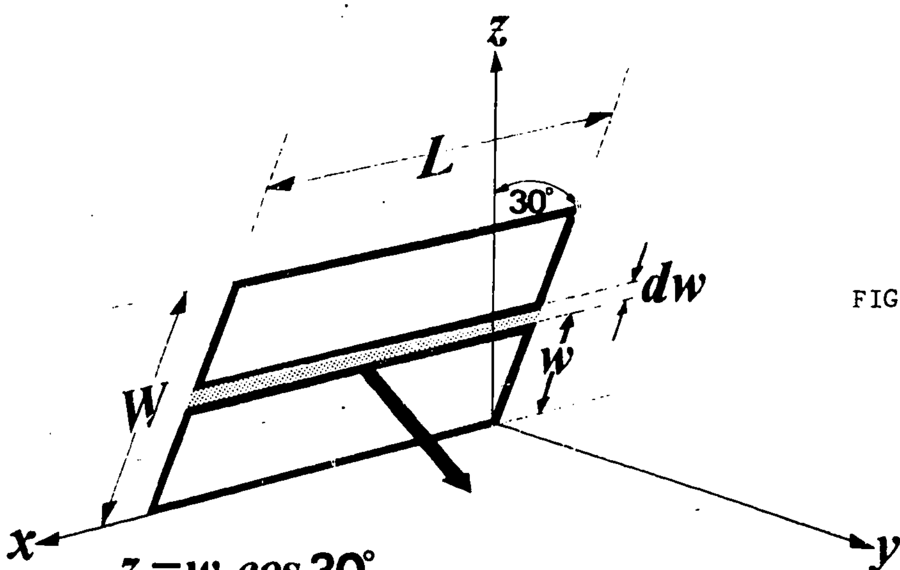


FIGURE (15)

$$z = w \cos 30^\circ$$
$$\vec{E} = \vec{a} z$$
$$= aw \cos 30^\circ$$

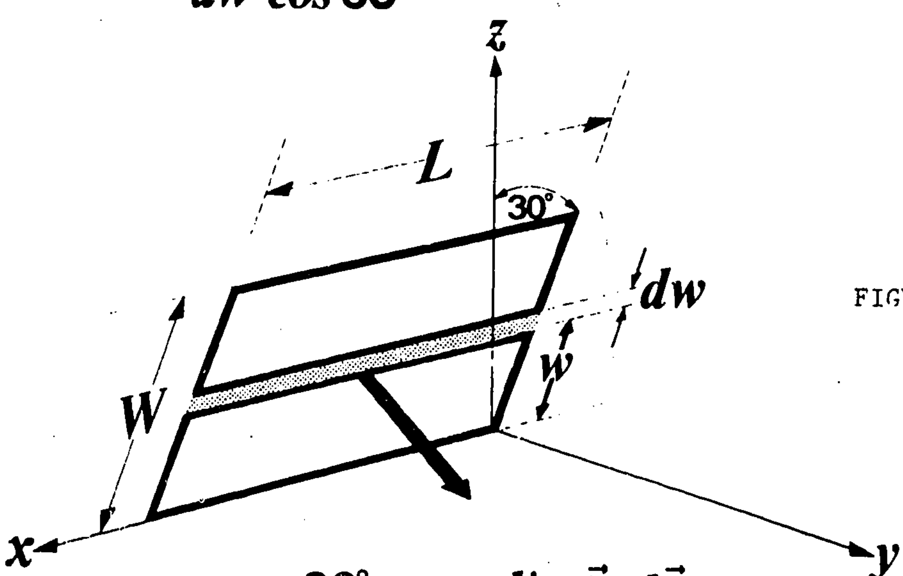


FIGURE (16)

$$z = w \cos 30^\circ$$
$$\vec{E} = \vec{a} z$$
$$= aw \cos 30^\circ$$

$$d\phi = \vec{E} \cdot d\vec{A}$$
$$= EL\, dw \cos 30^\circ$$
$$= awL \cos^2 30^\circ\, dw$$

$$d\phi = awL\cos^2 30^\circ\, dw$$

$$\phi = \int_0^W awL\cos^2 30^\circ\, dw$$

FIGURE 17

$$d\phi = awL\cos^2 30^\circ\, dw$$

$$\phi = \int_0^W awL\cos^2 30^\circ\, dw$$

$$= \tfrac{1}{2}\, aW^2 L\cos^2 30^\circ$$

FIGURE 18

FLUX

TERMINAL OBJECTIVES

10/1 A Answer questions and solve problems concerning electric field flux.

CALCULATION OF $\vec{E}$ USING GAUSS' LAW

$q = \lambda L$ $\qquad\qquad$ $q = \sigma A$

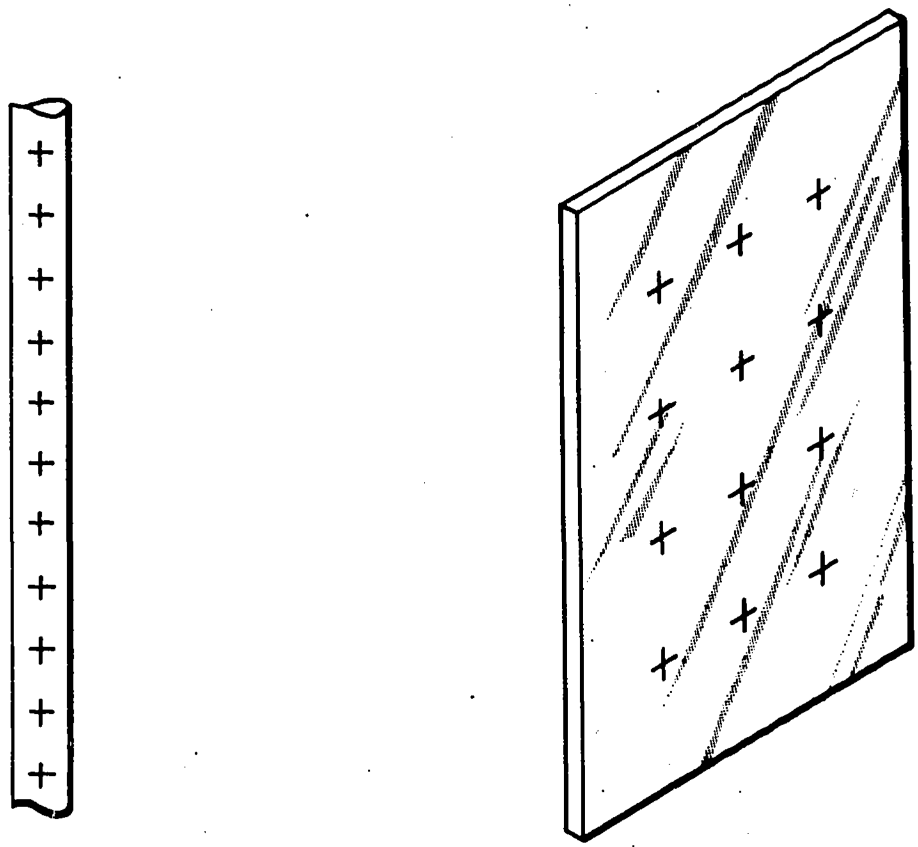


FIGURE 1

STRATEGY

(1) *Draw a closed symmetrical surface around the charge*

(2) *GAUSS' LAW*

$\phi = q/\epsilon_0$

FIGURE 2

STRATEGY

(1) *Draw a closed symmetrical surface around the charge*

(2) *GAUSS' LAW*

$\phi = q/\epsilon_0$

(3) $\phi = \int \vec{E} \cdot d\vec{A}$

FIGURE 3

$$\Phi = \int \vec{E} \cdot d\vec{A} = EA$$

FIGURE 4

CHARGE DENSITY = λ

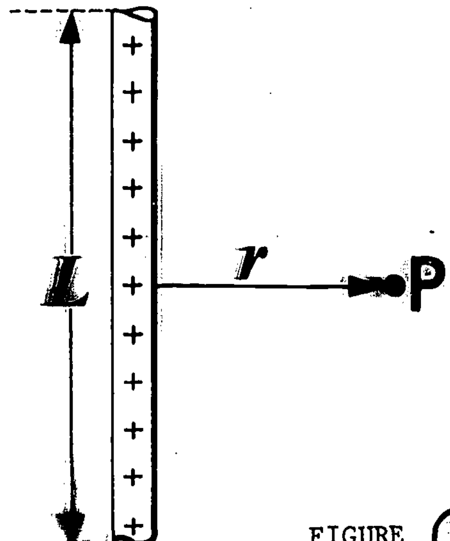


FIGURE 5

CHARGE DENSITY = λ

$$q = \lambda L$$
$$\phi = \lambda L / \epsilon_0$$

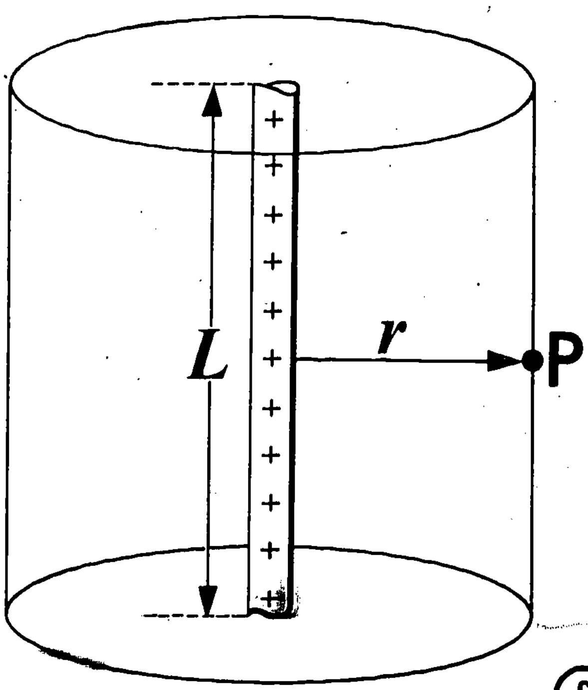
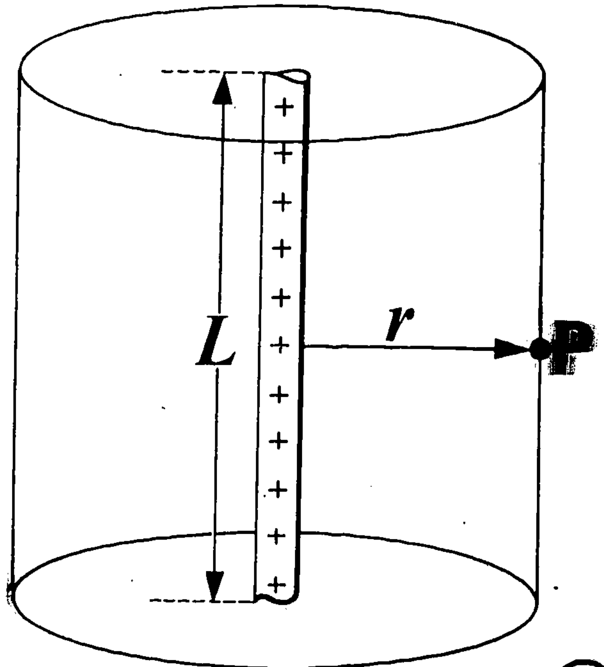


FIGURE 6

CHARGE DENSITY = λ



$$q = \lambda L$$

$$\phi = \lambda L / \epsilon_0$$

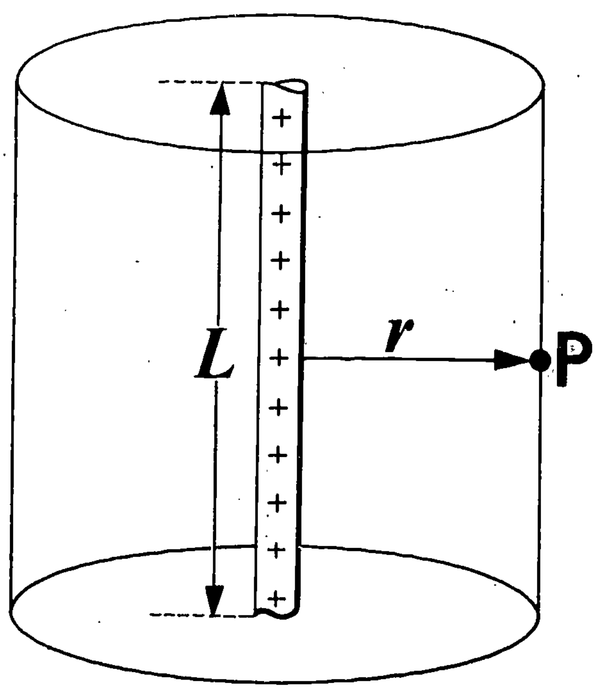
$$\phi = EA$$

$$= E\,2\pi r L$$

FIGURE (7)

CHARGE DENSITY = λ

$$E = \frac{1}{2\pi\epsilon_0}\,\frac{\lambda}{r}$$



$$\phi = EA$$

(1) $\phi = 2\pi r L E$

$$\phi = q / \epsilon_0$$

$$q = \lambda L$$

(2) $\phi = \lambda L / \epsilon_0$

(3) $2\pi r L E = \lambda L / \epsilon_0$

$$E = \frac{\lambda}{2\pi\epsilon_0 r}$$

FIGURE (8)

CHARGE DENSITY = σ

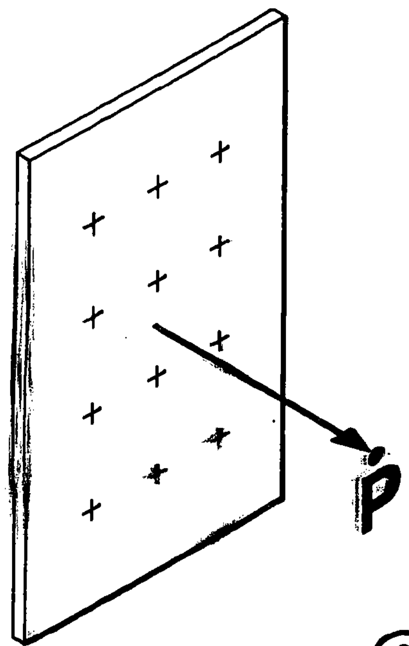


FIGURE 9

CHARGE DENSITY = σ

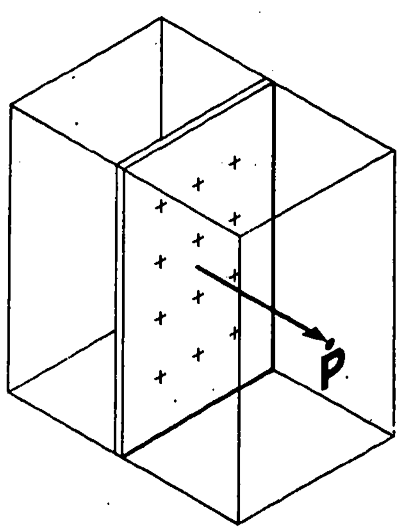
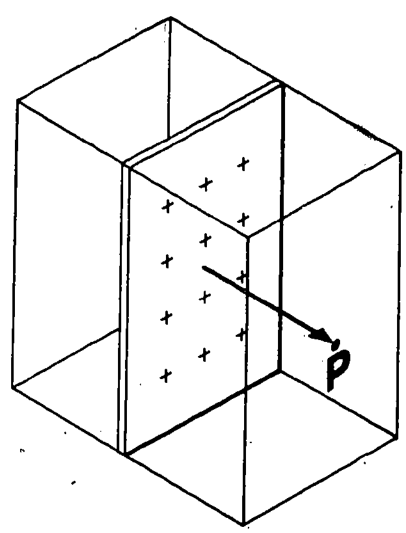


FIGURE 10

CHARGE DENSITY = σ



$$q = \sigma A$$

$$\Phi = \frac{\sigma A}{\epsilon_0}$$

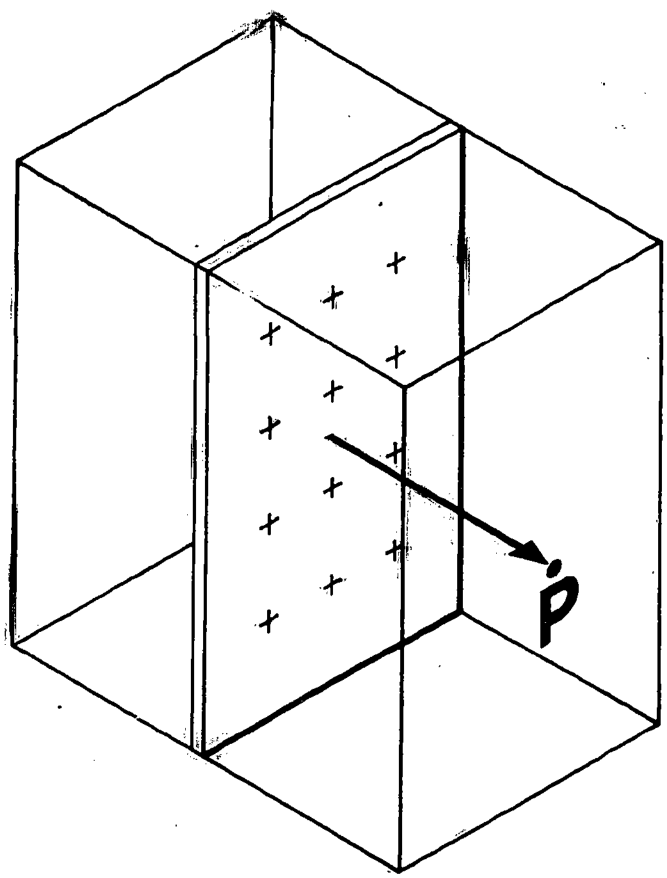
$$(4)\quad q = \sigma A$$

$$(5)\quad \Phi = \frac{q}{\epsilon_0}$$

$$(6)\quad \Phi = \frac{\sigma A}{\epsilon_0}$$

FIGURE 11

CHARGE DENSITY = σ



$$q = \sigma A$$

$$\phi = \frac{\sigma A}{\epsilon_0}$$

(4) $q = \sigma A$

(5) $\phi = \frac{q}{\epsilon_0}$

(6) $\phi = \frac{\sigma A}{\epsilon_0}$

(7) $\phi = 2EA$

$$2EA = \frac{\sigma A}{\epsilon_0}$$

$$E = \frac{\sigma}{2\epsilon_0}$$

FIGURE 12

CALCULATION OF $\vec{E}$ USING GAUSS' LAW

TERMINAL OBJECTIVES

10/2 A Answer questions and solve problems using Gauss's Law for cases of spherically symmetric charge distributions.

10/2 E Apply Gauss' Law to charged bodies.

CAPACITORS

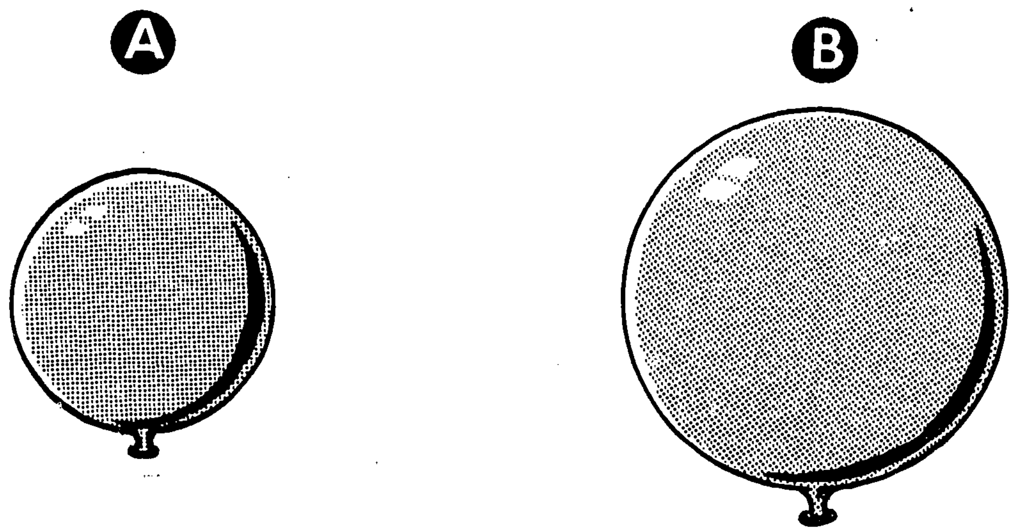


FIGURE 1

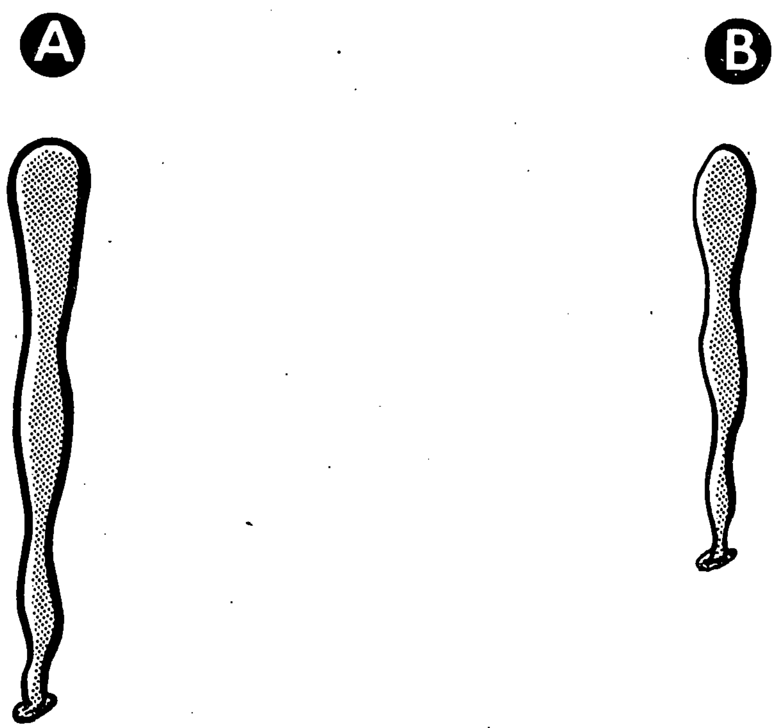


FIGURE 2

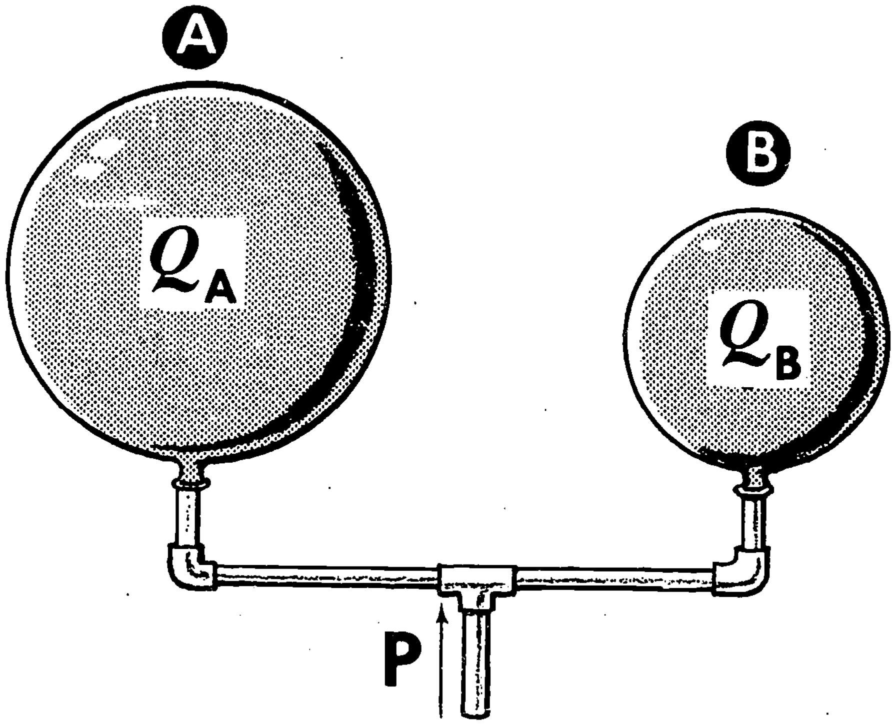


FIGURE 3

WITH PRESSURE CONSTANT

$$\frac{Q_A}{C_A} = \frac{Q_B}{C_B}$$

OF $Q = PC$

SO $C = \dfrac{Q}{P}$

FIGURE 4

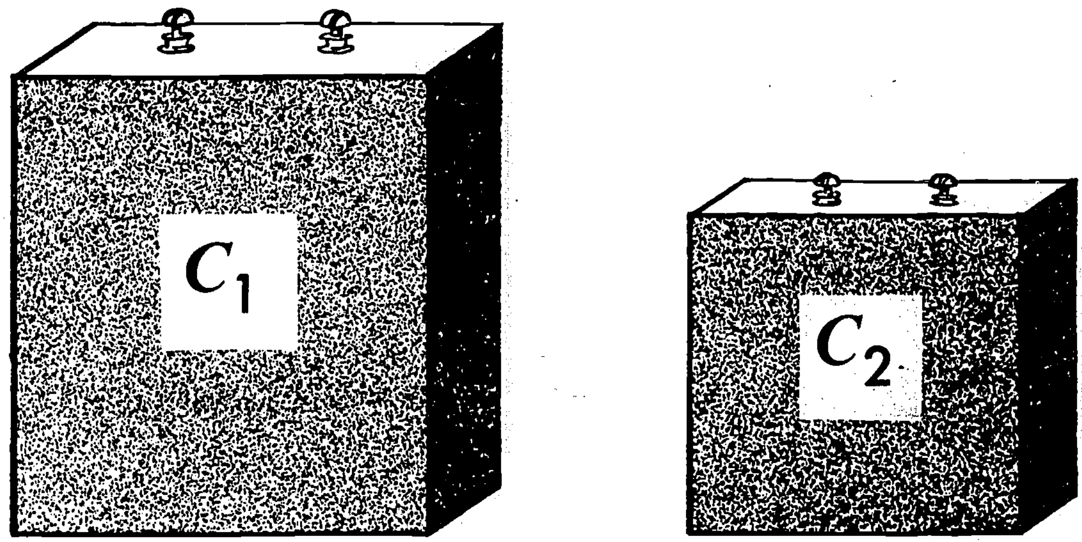


FIGURE 5

$$\frac{Q_1}{C_1} = \frac{Q_2}{C_2} \quad (V = k)$$

$$\text{so} \quad C = \frac{Q}{V}$$

FIGURE 6

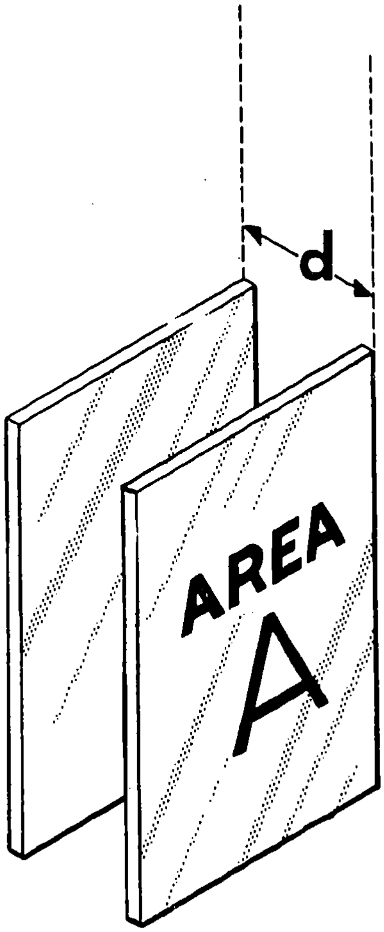


FIGURE 7

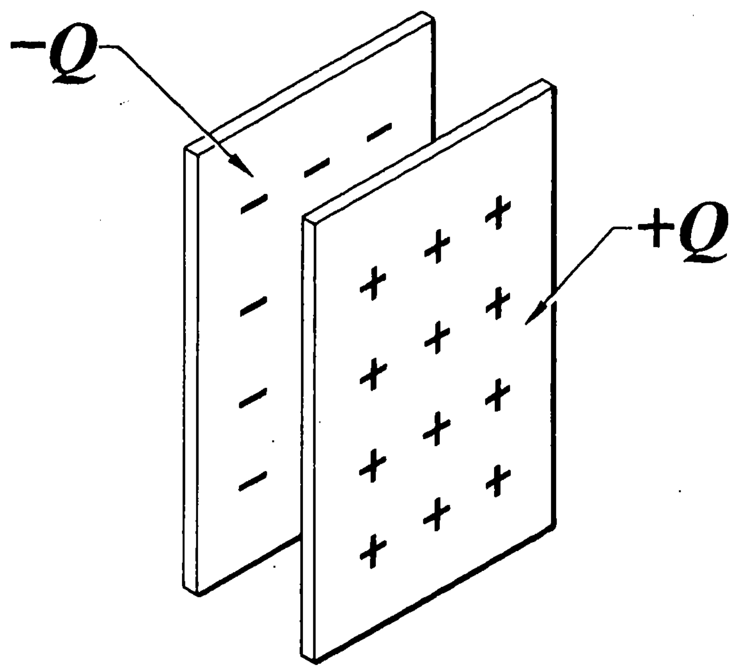


FIGURE 8

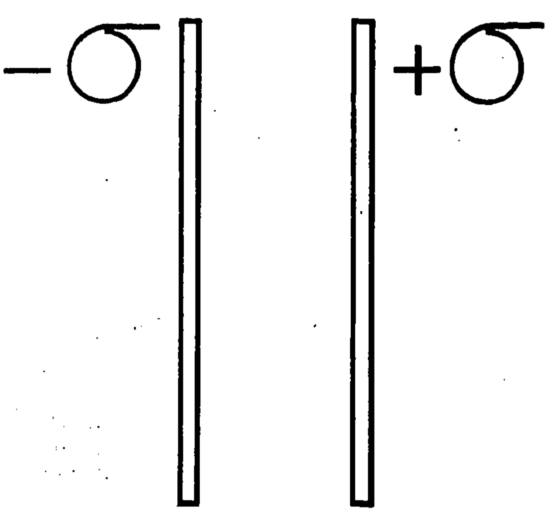
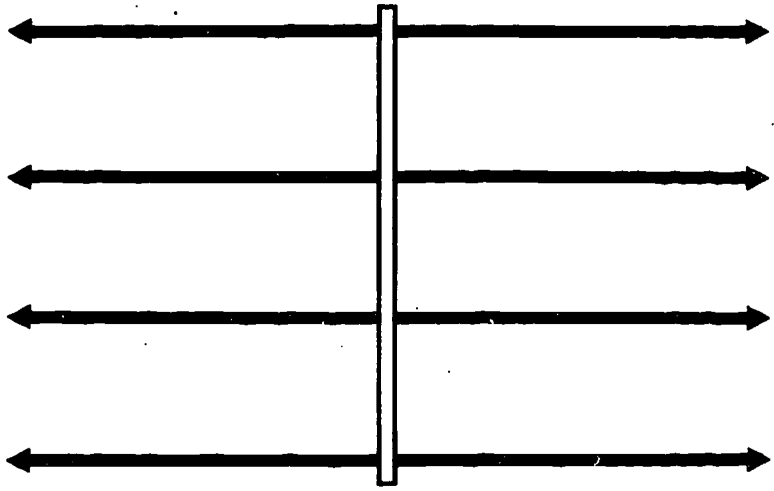
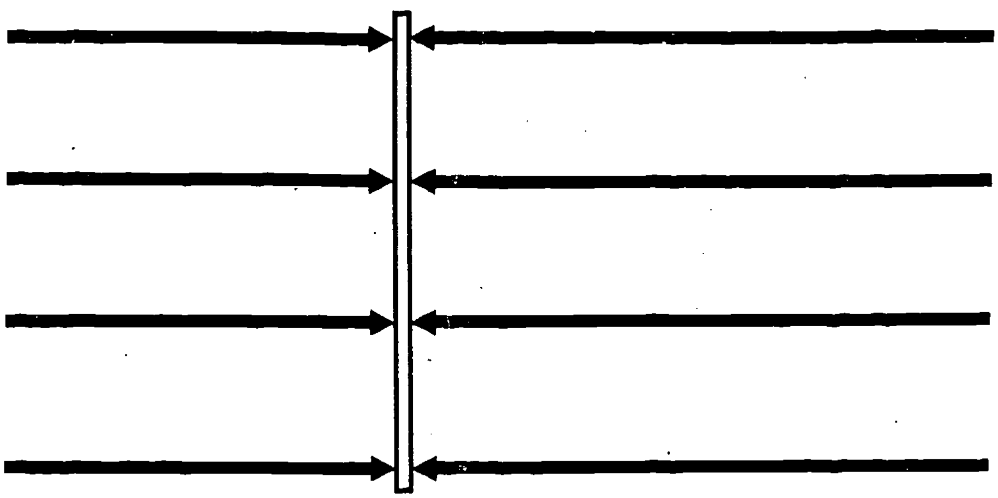


FIGURE 9



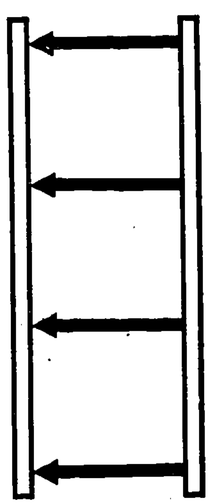
$$E = \frac{+\sigma}{2\epsilon_0}$$

FIGURE 10



$$E = \frac{-\sigma}{2\pi\epsilon_0}$$

FIGURE 11



$$E = \frac{\sigma}{2\epsilon_0} + E = \frac{\sigma}{2\epsilon_0}$$

$$E = \frac{\sigma}{\epsilon_0}$$

FIGURE 12

FIGURE 13

$$E = \frac{\sigma}{\epsilon_0}$$

$$V = \int_0^d E \cdot dl$$

$$= E\,d$$

$$= \frac{\sigma}{\epsilon_0}\,d$$

$$V = \frac{\sigma}{\epsilon_0}\,d$$

FIGURE 14

$$Q = \sigma A$$

FIGURE 15

$$C = \frac{Q}{V}$$

$$= \frac{\sigma A}{\sigma d/\epsilon_0}$$

$$= \frac{\epsilon_0 A}{d}$$

CAPACITORS

TERMINAL OBJECTIVES

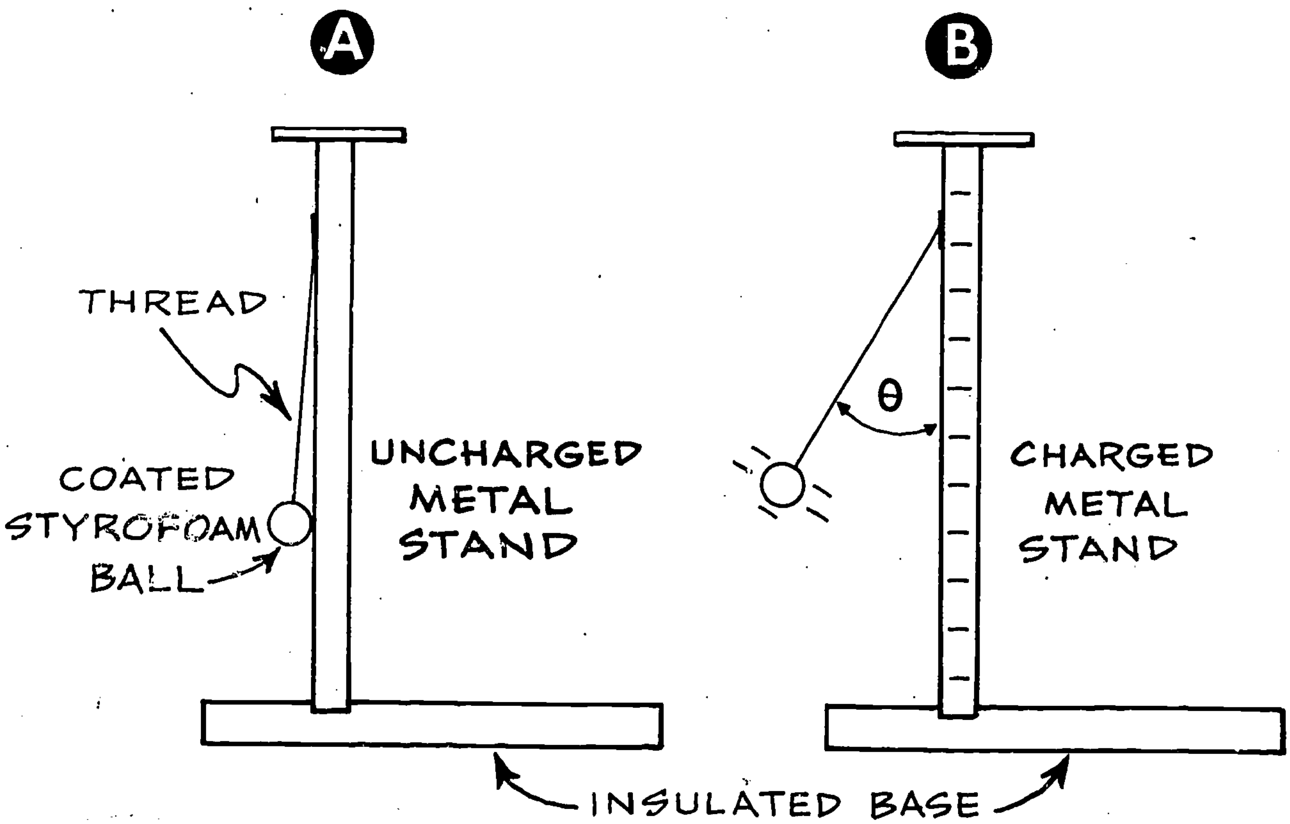
11/3 A Answer questions and solve numerical problems involving the physical significance and units (basic and submultiples) of capacitance, C.

11/3 D Solve problems involving various conductor-pair geometries' and the corresponding capacitances.

12/1 A Solve discriptive and numerical problems involving capacitors in series and parallel combinations. (Note: All interconnecting wires are resistanceless).

12/1 D Predict the effect of adding a dielectric of known dimensions and material to a vacuum capacitor in both descriptive and quantitative situations.

THE CAPACITOR IN ACTION



A
B
THREAD
COATED
STYROFOAM
BALL
UNCHARGED
METAL
STAND
θ
CHARGED
METAL
STAND
INSULATED BASE

FIGURE 1

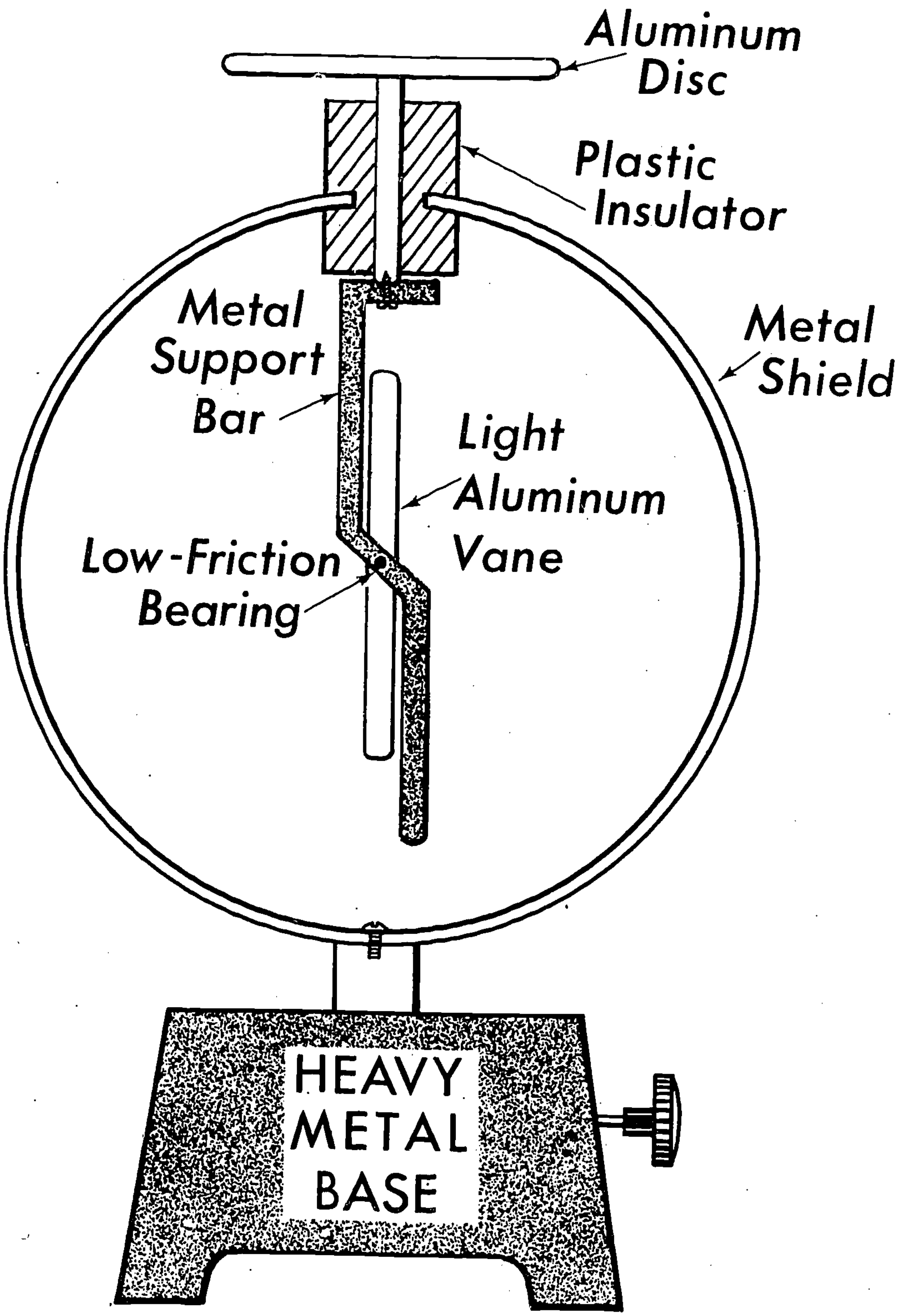
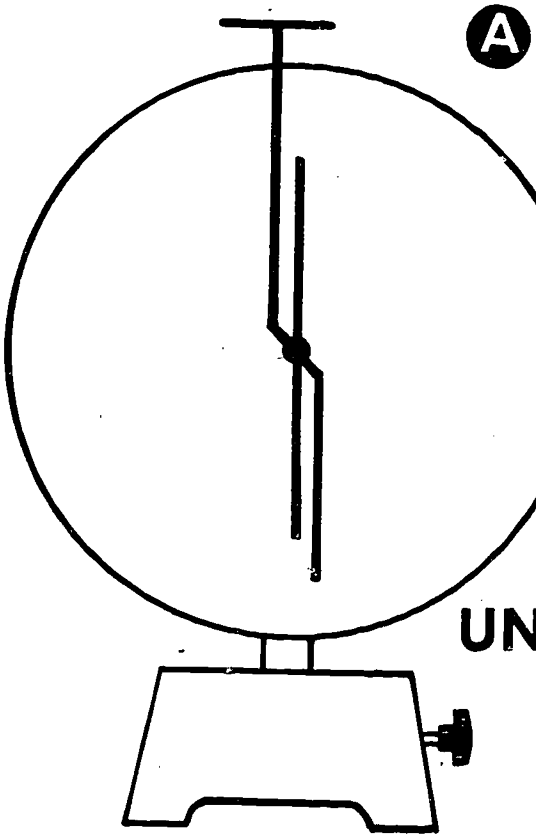

Aluminum Disc
Plastic Insulator
Metal Support Bar
Metal Shield
Light Aluminum Vane
Low-Friction Bearing
HEAVY METAL BASE

FIGURE 2



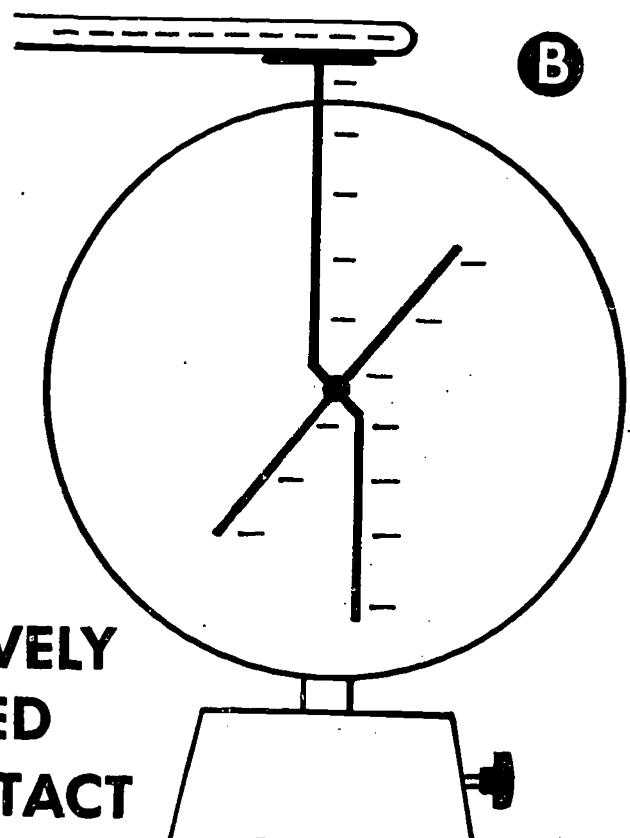


FIGURE 3

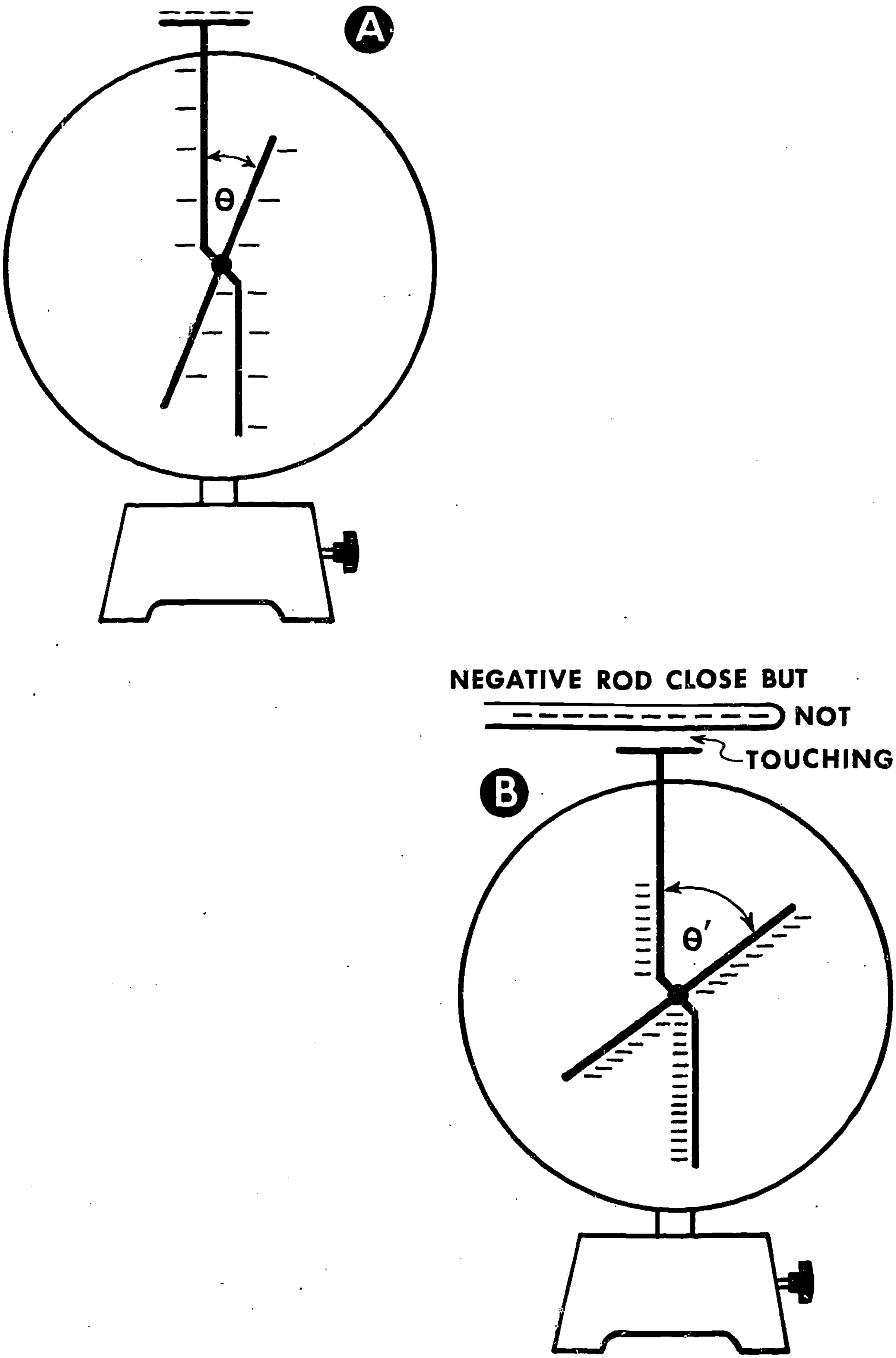


FIGURE 4

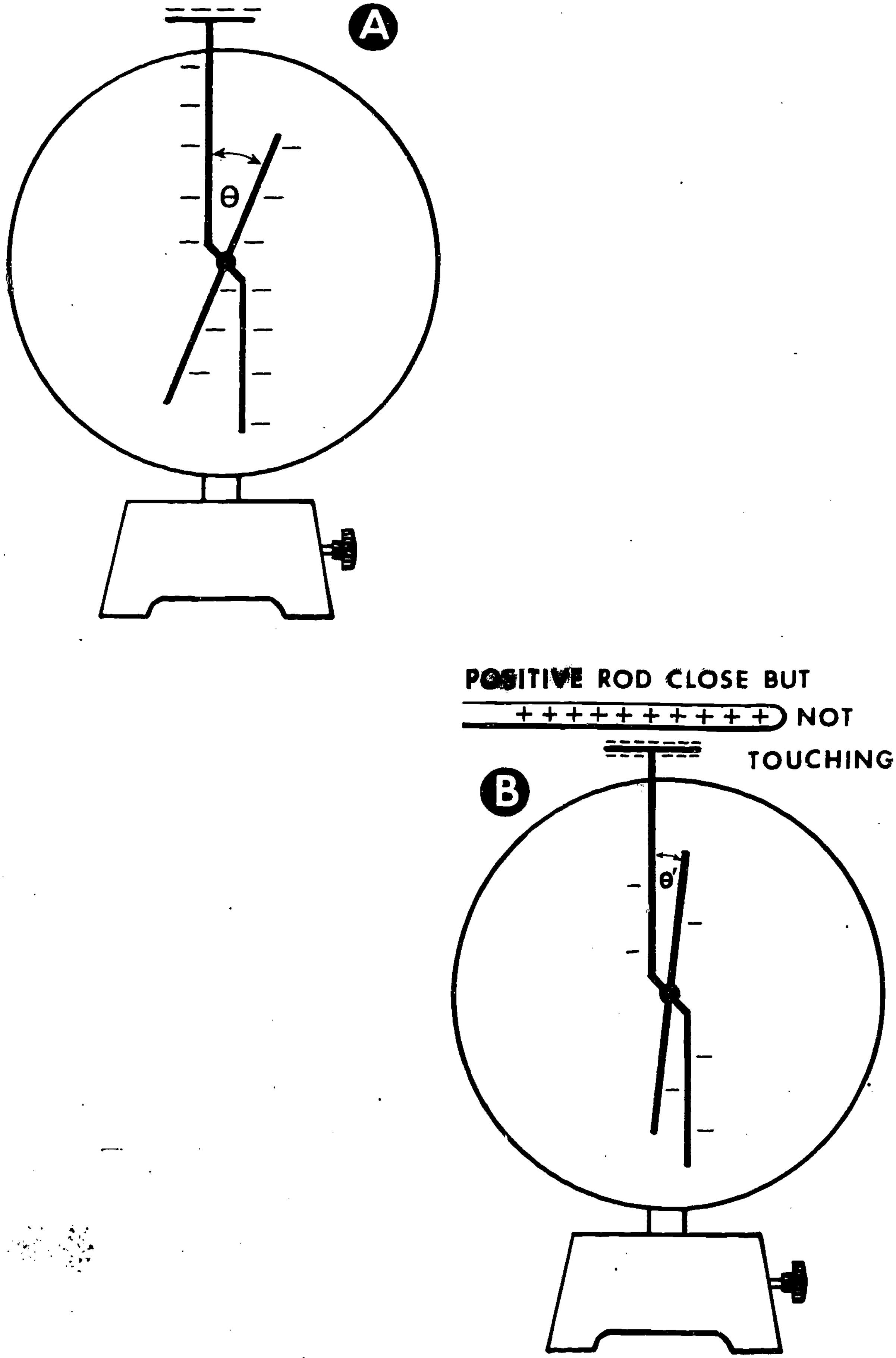
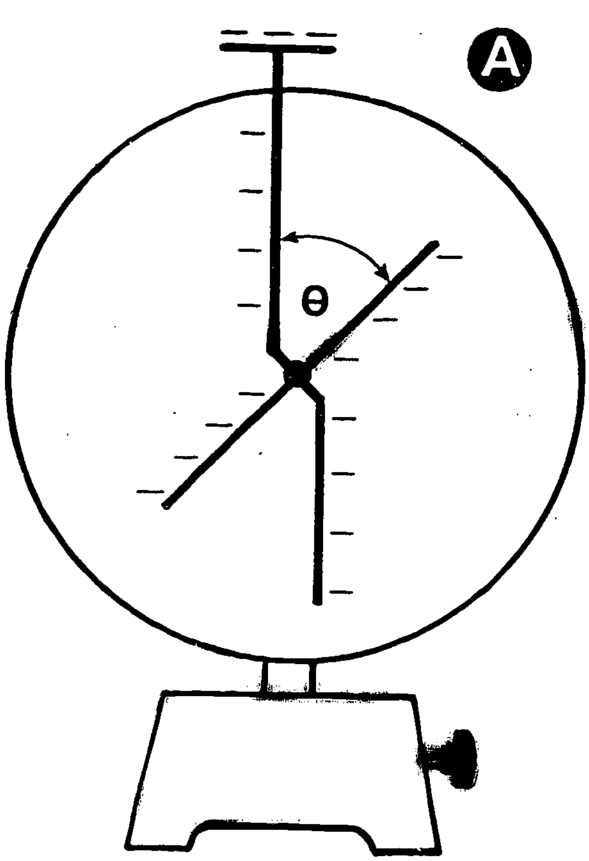


FIGURE 5



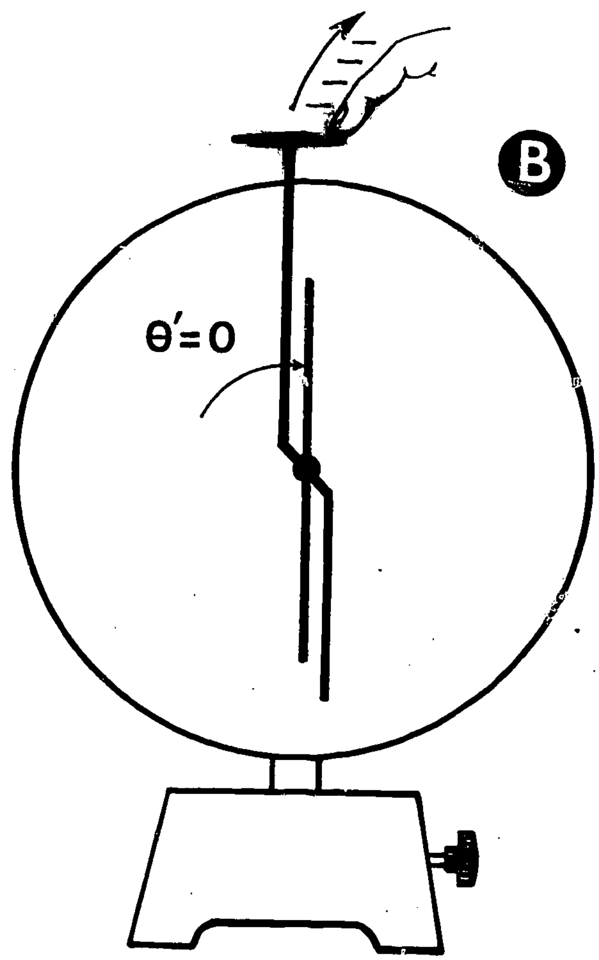
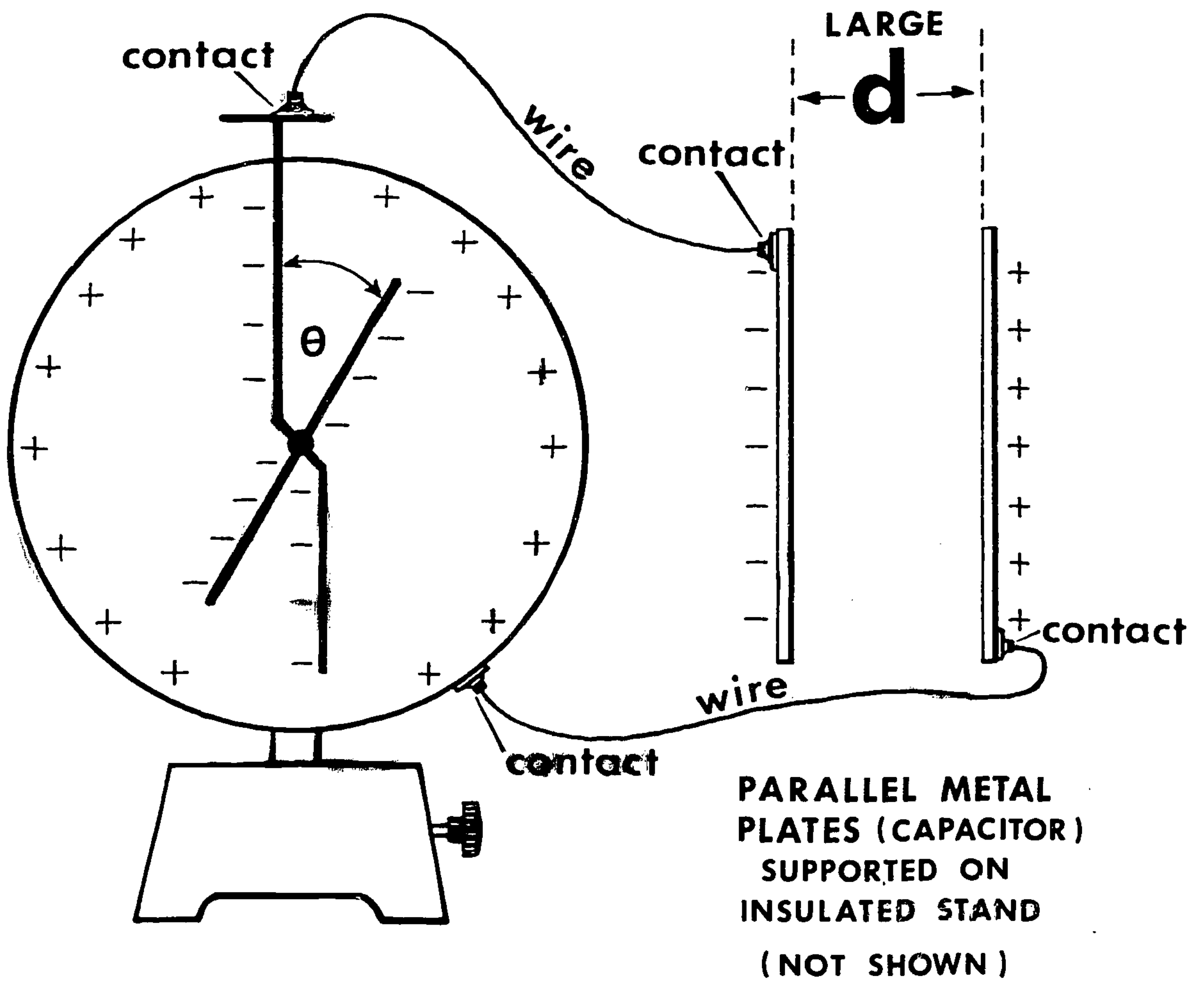


FIGURE 6

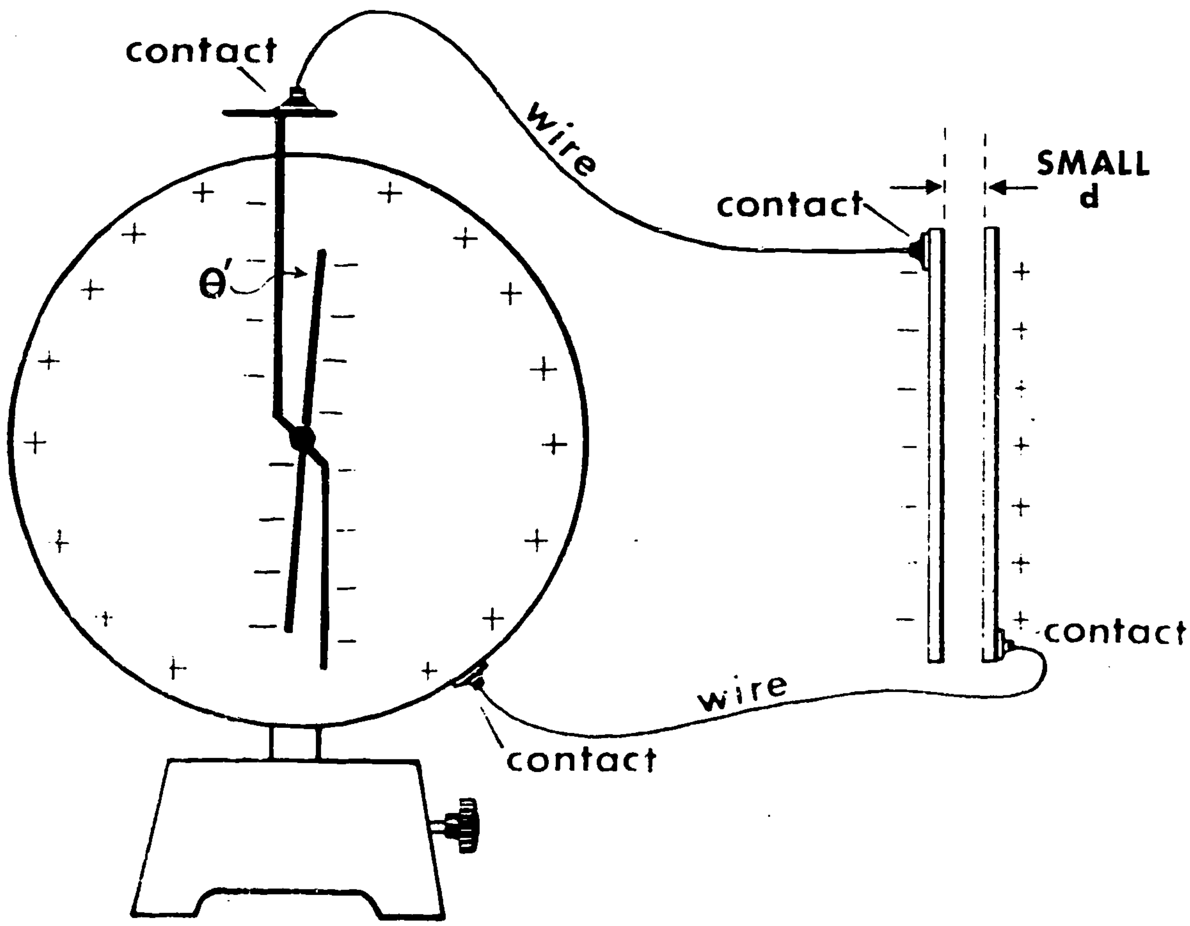


$$(1)\quad C = K\epsilon_0 \frac{A}{d}$$

$$(2)\quad V = \frac{Q}{C}$$

(V is measured by θ)

FIGURE 7



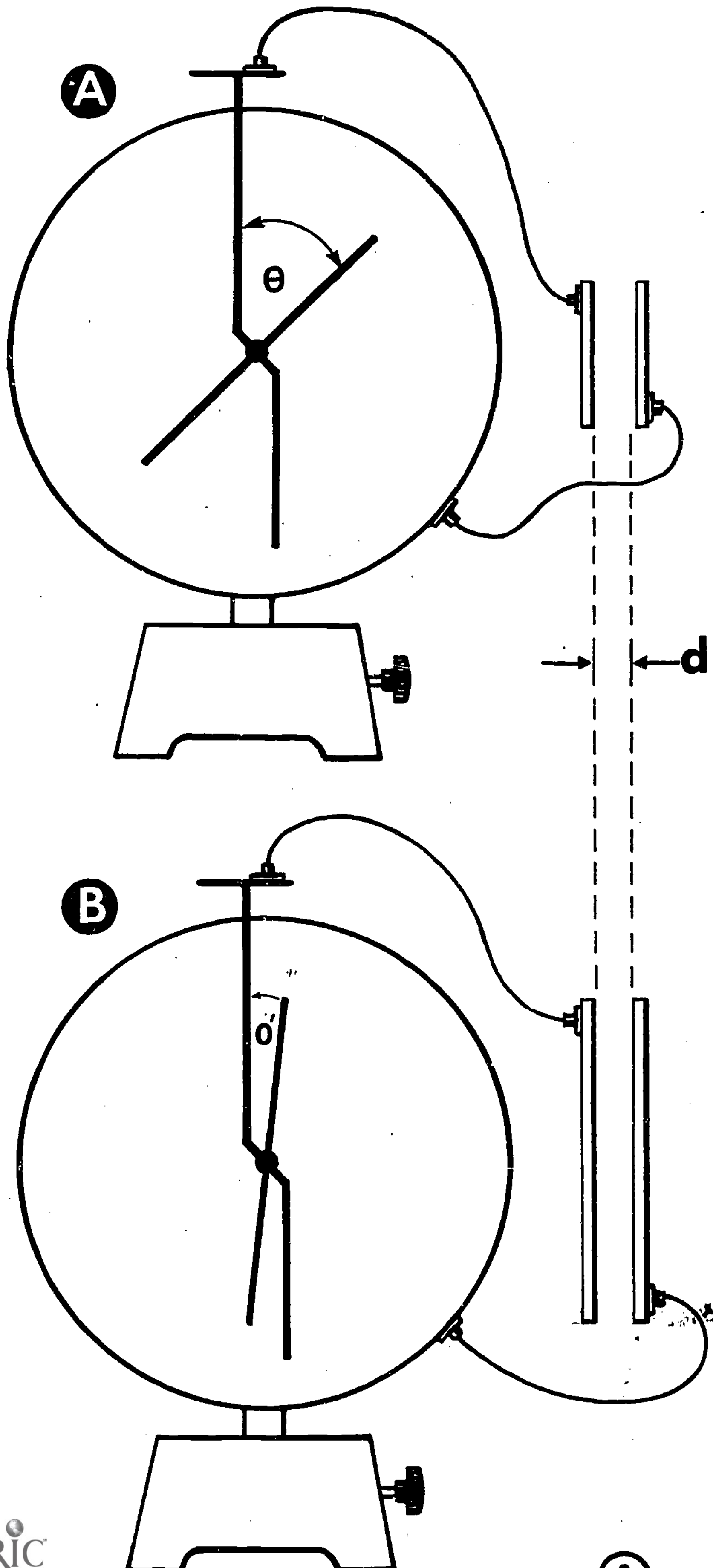
The Changes

$$(1)\quad C = K\epsilon_0 \frac{A}{\mathbf{d}} \longrightarrow \mathbf{C} = K\epsilon_0 \frac{A}{d}$$

$$(2)\quad V = \frac{Q}{C} \longrightarrow v = \frac{Q}{\mathbf{C}}$$

$$\text{hence } \boldsymbol{\theta} \longrightarrow \theta'$$

FIGURE 8



The Changes

(1) $C = K\epsilon_0 \frac{A}{d}$

(2) $V = \frac{Q}{C}$

θ = as shown

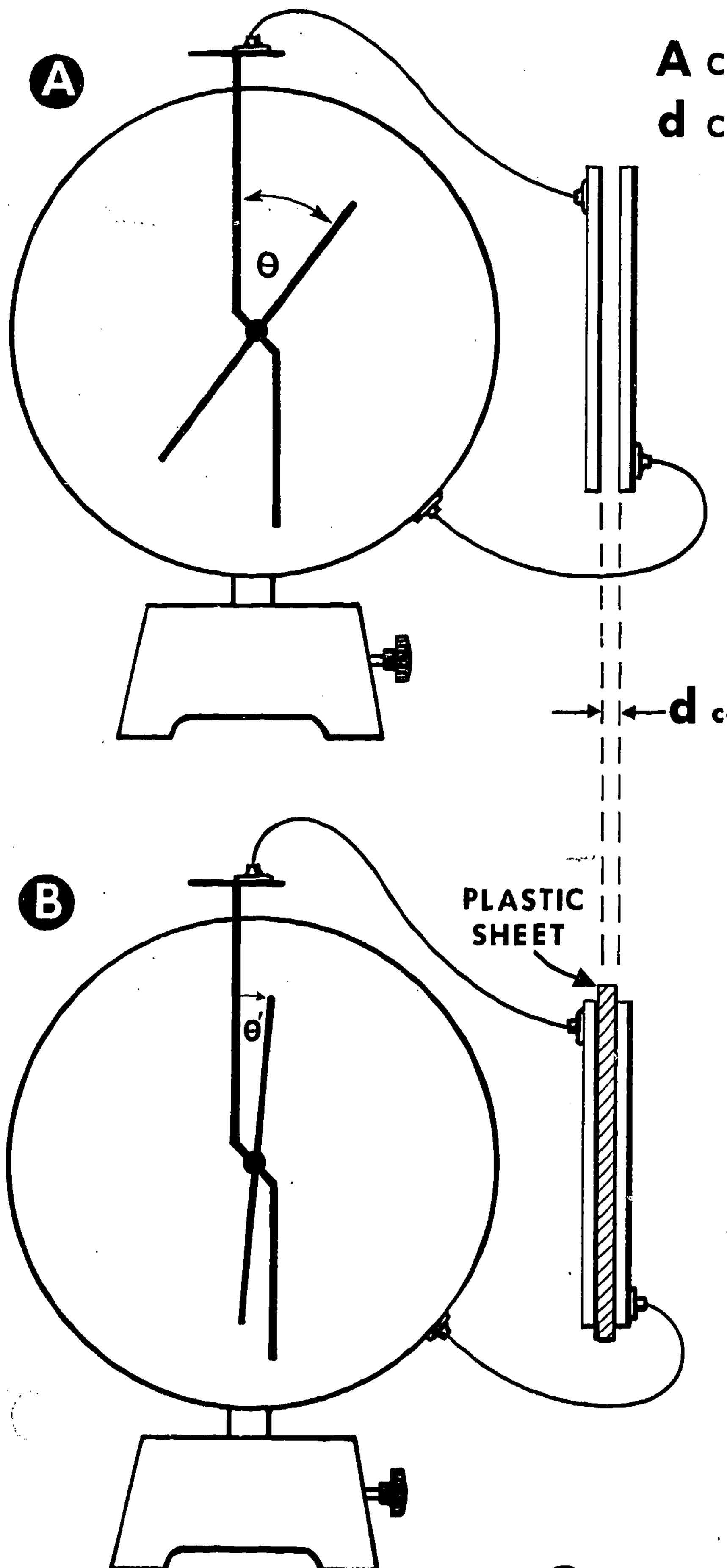
The Changes

(1) $\mathbf{C} = K\epsilon_0 \frac{\mathbf{A}}{d}$

(2) $v = \frac{Q}{\mathbf{C}}$

θ' is smaller than θ

FIGURE 9



A CONSTANT

d CONSTANT

$$(1)\quad C = K\epsilon_0 \frac{A}{d}$$

$$(2)\quad V = \frac{Q}{C}$$

θ = as shown

The Changes

$$(1)\quad \mathbf{C} = \mathbf{K}\epsilon_0 \frac{A}{d}$$

$$(2)\quad v = \frac{Q}{\mathbf{C}}$$

θ' is smaller than θ

FIGURE 10

THE CAPACITOR IN ACTION

TERMINAL OBJECTIVES:

11-1.080-00

Solve descriptive and numerical problems involving capacitors in series and parallel combinations. (Note: All interconnecting wires are resistanceless)

11-1.083-00

Predict the effect of adding a dielectric of known dimensions and material to a vacuum capacitor in both descriptive and quantitative situations.

KIRCHHOFF'S RULES

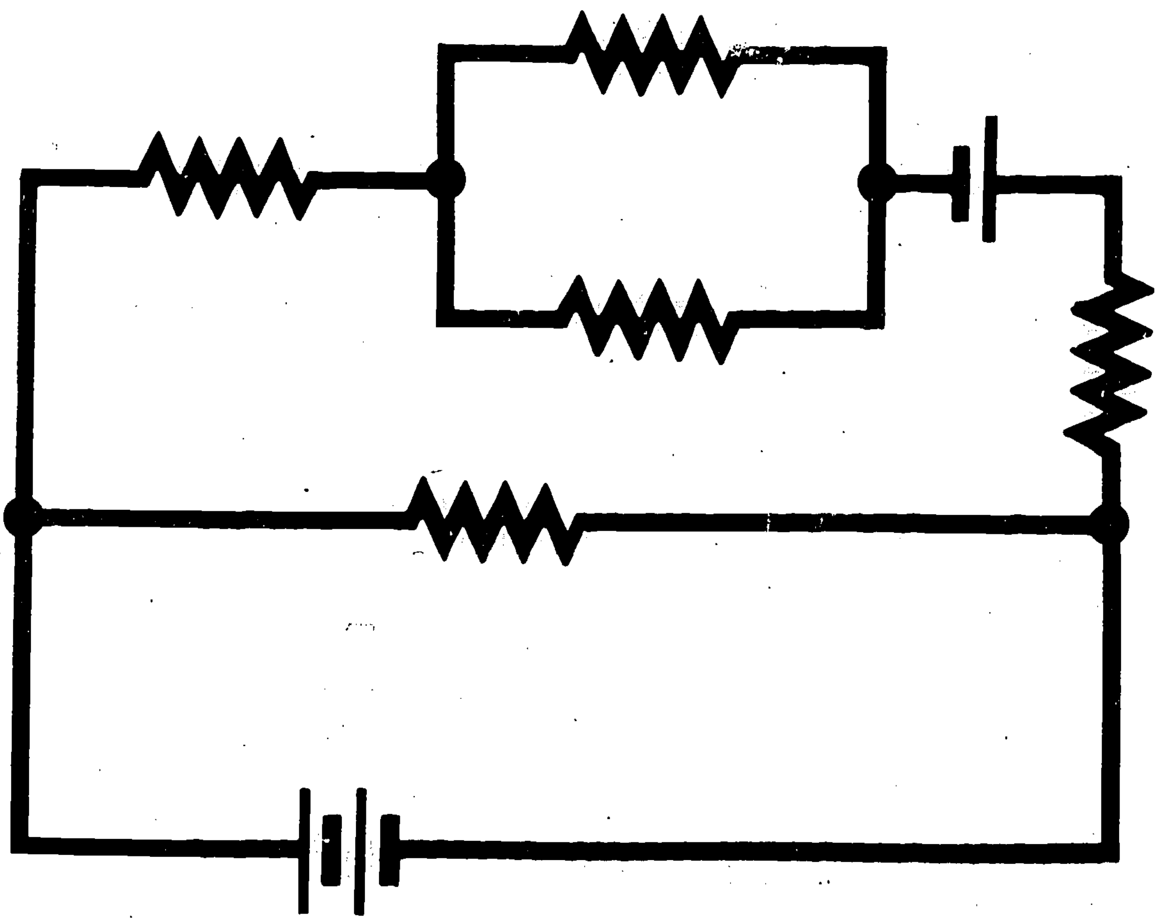


FIGURE 1

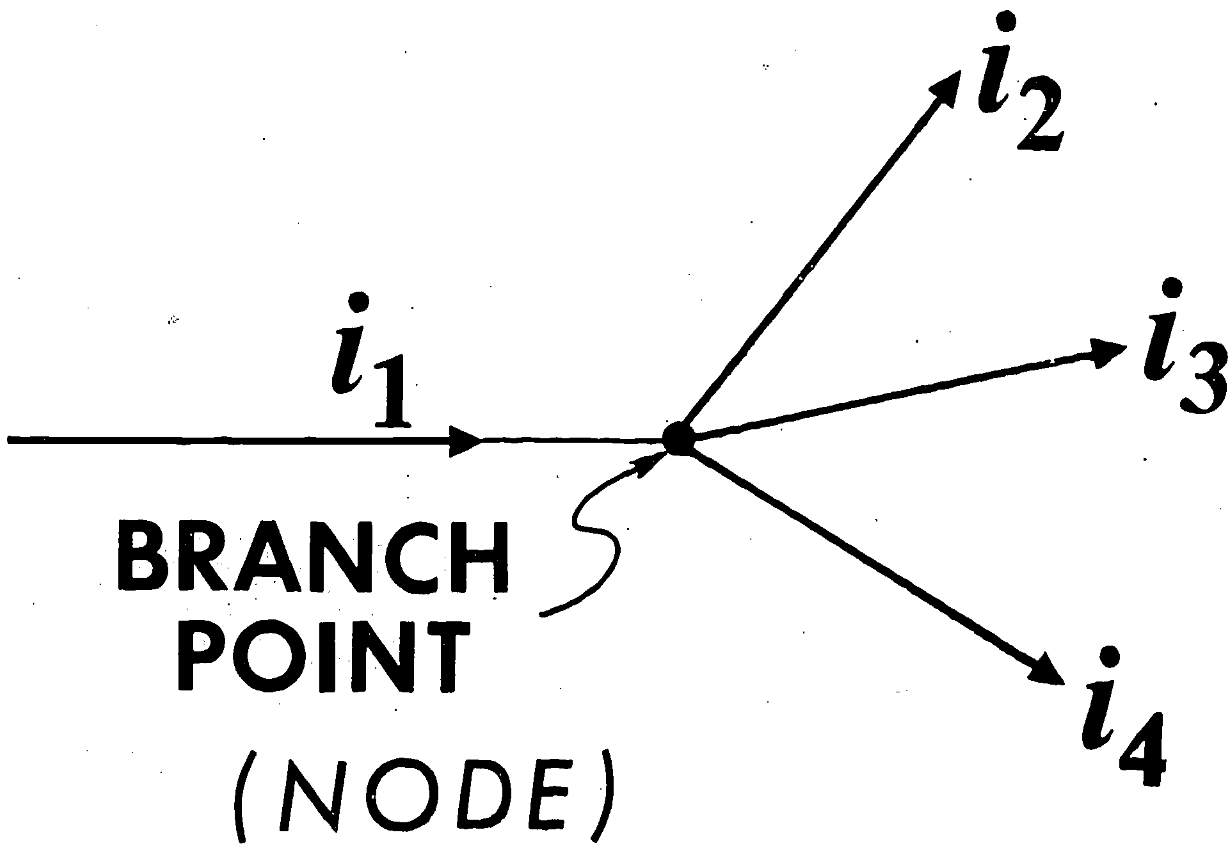


FIGURE 2

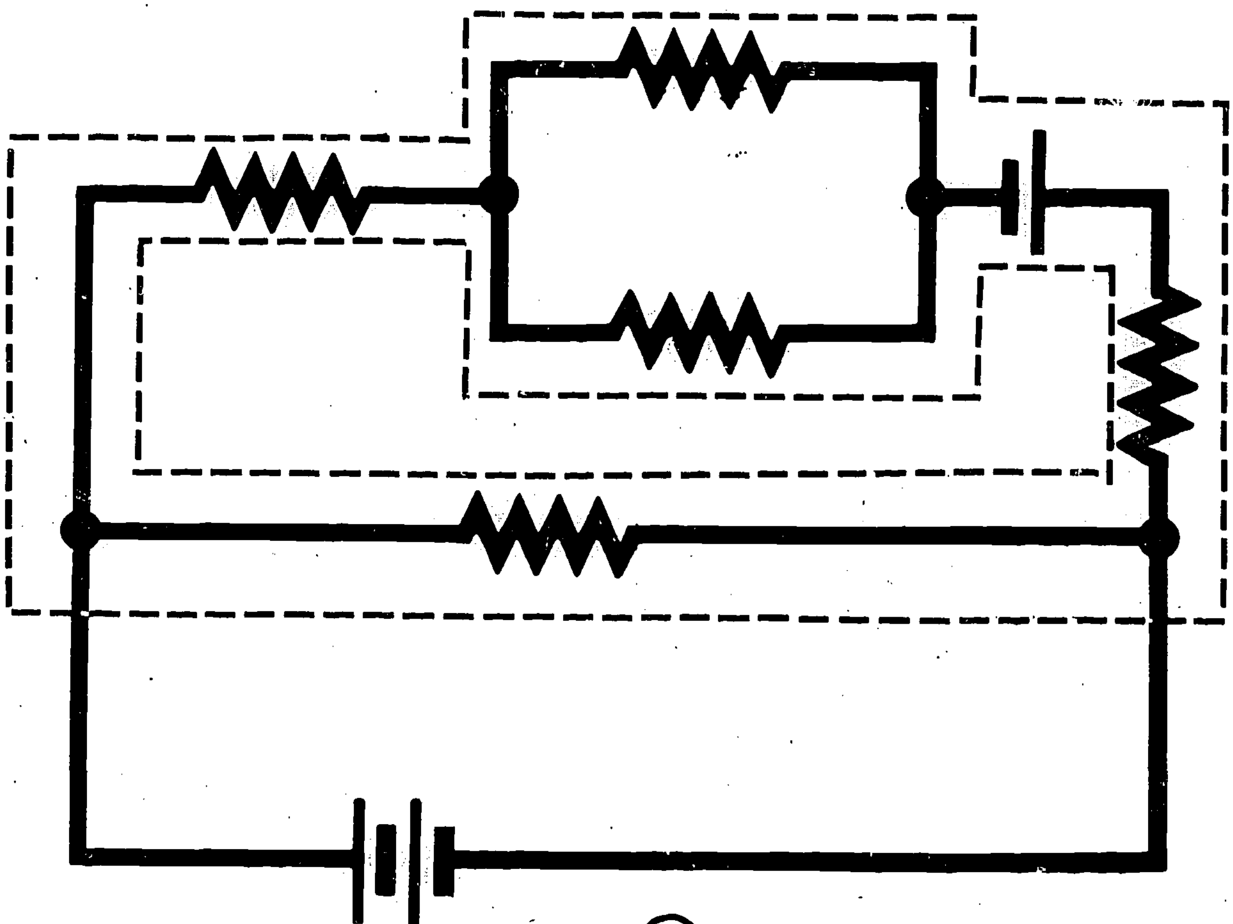


FIGURE 3

KIRCHHOFF'S RULES

1. AT ANY JUNCTION, THE ALGEBRAIC SUM OF THE CURRENTS MUST BE ZERO.

FIGURE 4

KIRCHHOFF'S RULES

2. THE SUM OF THE CHANGES IN POTENTIAL ENCOUNTERED IN MAKING A COMPLETE LOOP IS ZERO.

FIGURE 5

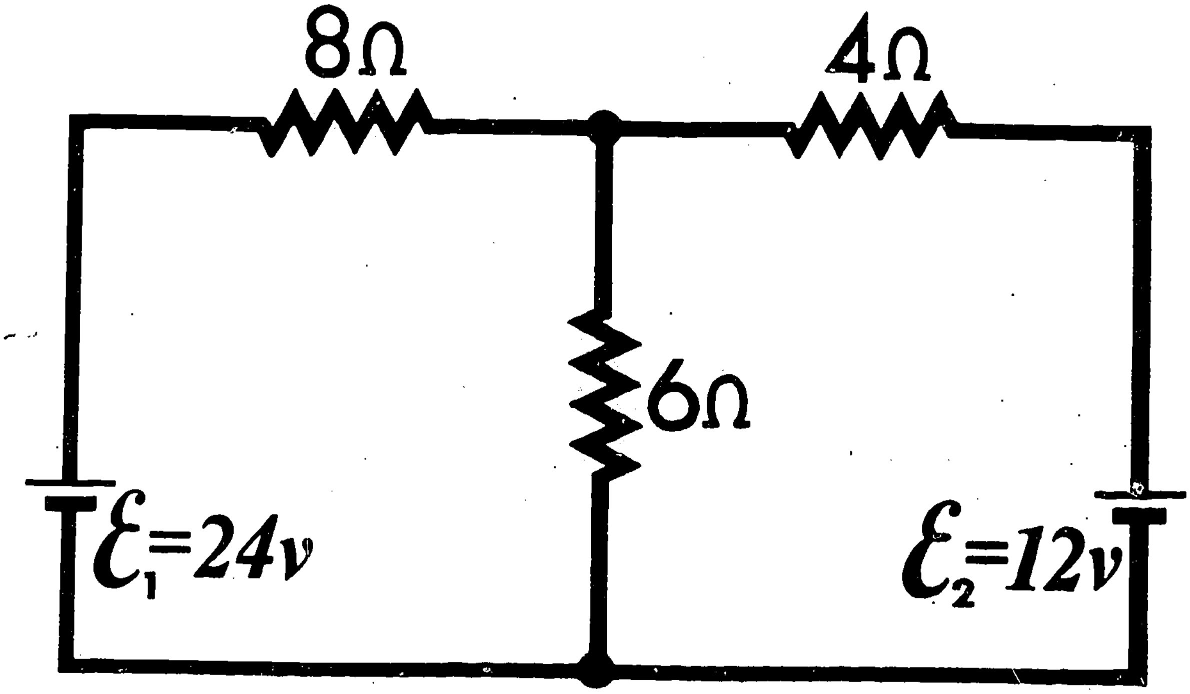


FIGURE 6

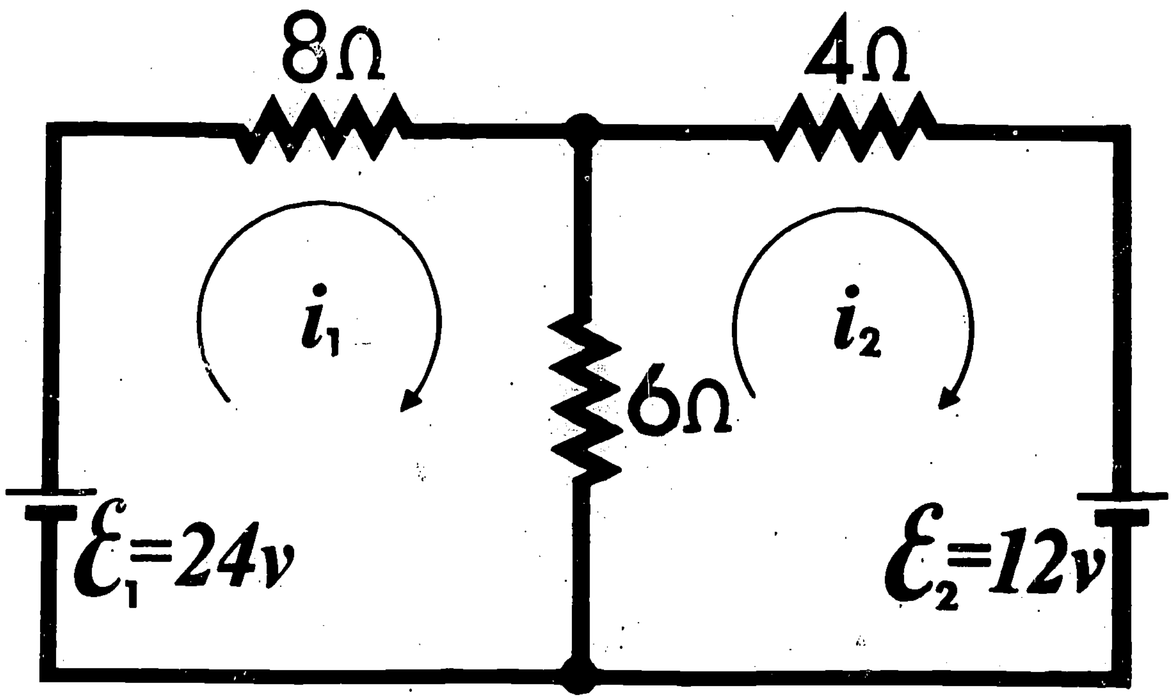


FIGURE 7

$$\mathcal{E}_1 = i_1 \left(8\Omega + 6\Omega\right) - i_2\, 6\Omega$$

$$24v = i_1\ 14\Omega - i_2\ 6\Omega$$

FIGURE 8

$$-\mathcal{E}_2 = i_2 \left(6\Omega + 4\Omega\right) - i_1\, 6\Omega$$

$$-12v = i_2\ 10\Omega - i_1\ 6\Omega$$

FIGURE 9

$$24v = i_1\ 14\Omega - i_2\ 6\Omega$$

$$-12v = i_2\ 10\Omega - i_1\ 6\Omega$$

FIGURE 10

$$i_1 = 1.62\ amps$$

$$i_2 = -.25\ amps$$

FIGURE 11

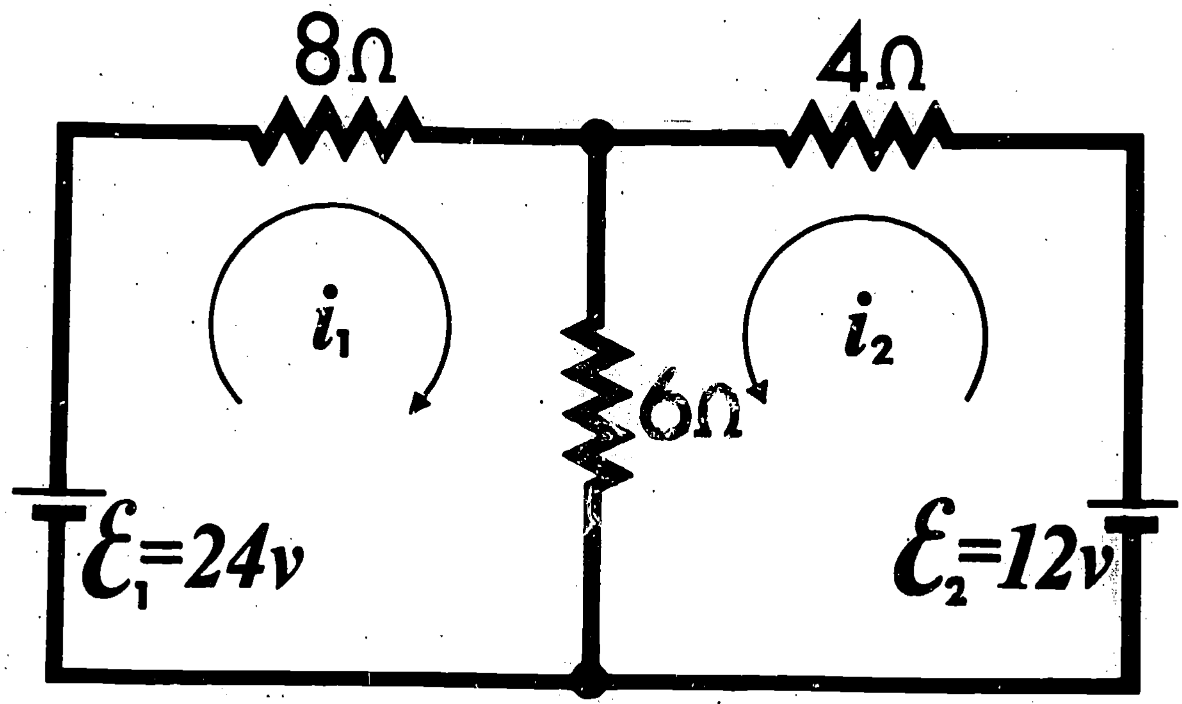


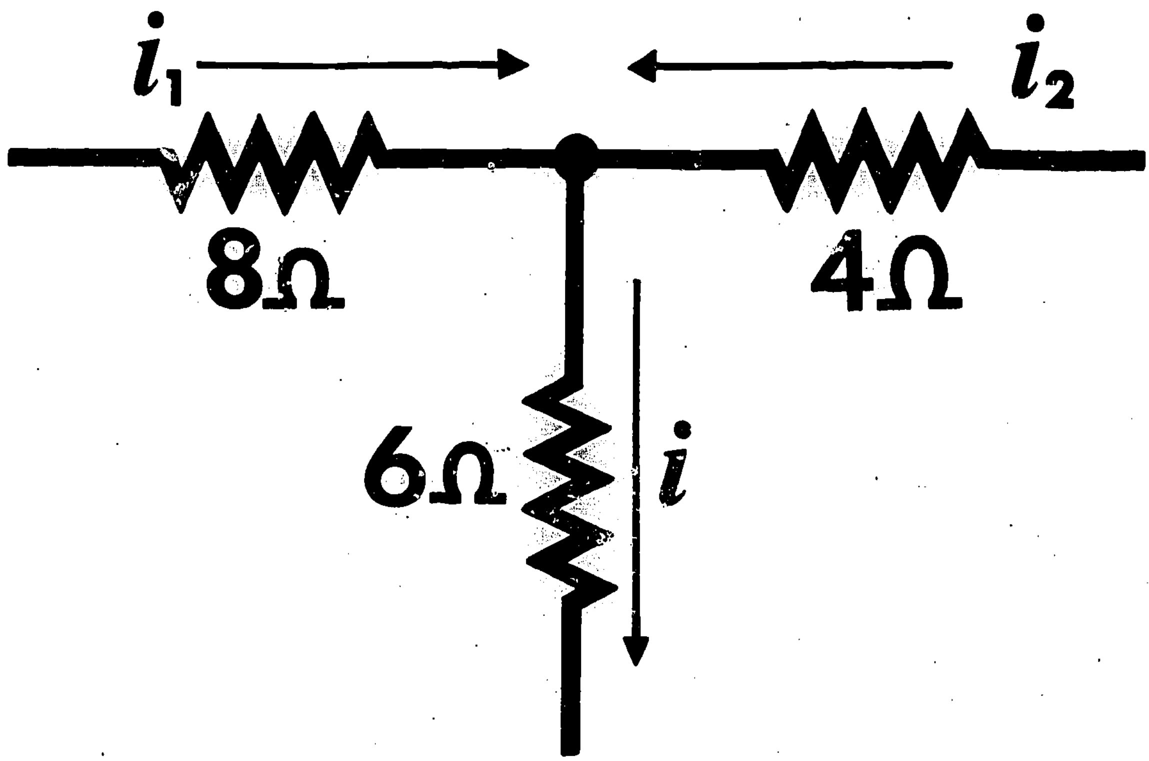
FIGURE 12

$$24v = i_1\ 14\Omega - i_2\ 6\Omega$$

$$-12v = i_2\ 10\Omega - i_1\ 6\Omega$$

$$\text{Hence}\ \ i_1 + i_2$$

FIGURE 13



$$i_1 + i_2 + i = 0$$

$$1.62\,amps + .25\,amps - i = 0$$

$$i = 1.87\,amps$$

FIGURE 14

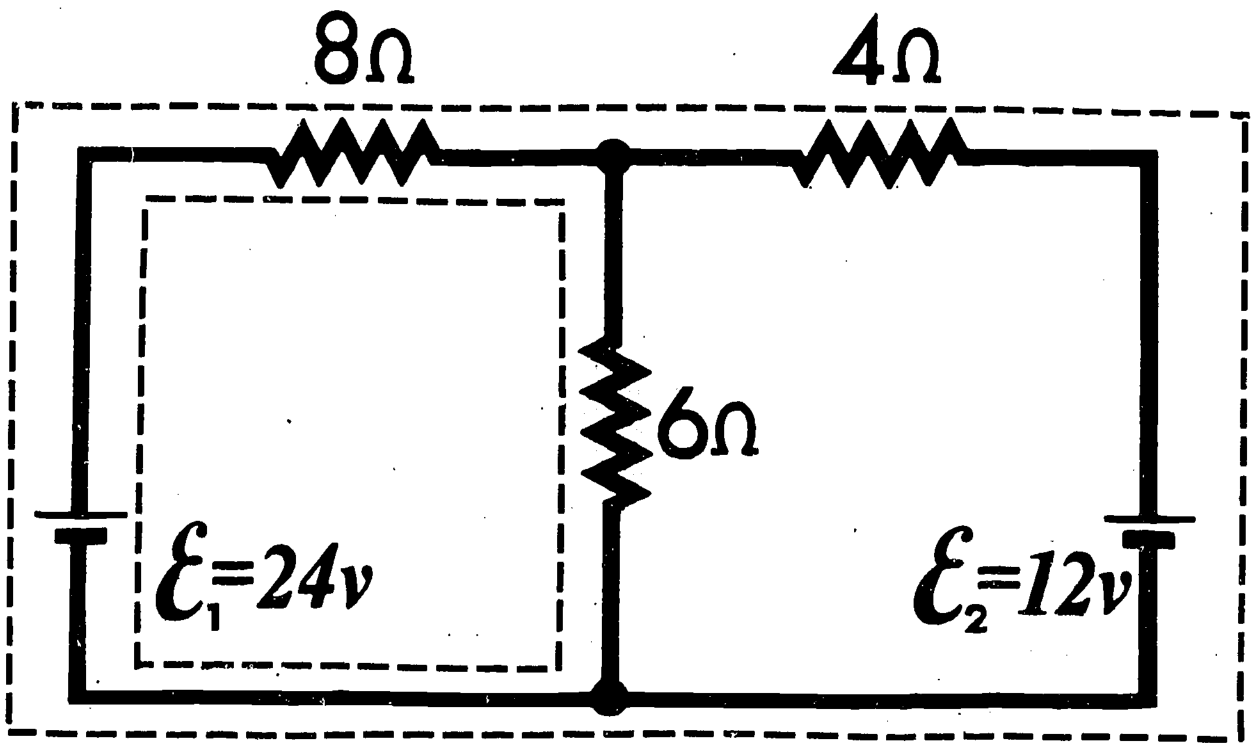


FIGURE 15

$$-\mathcal{E}_1 = i_1\, 6\Omega + i_1\, 8\Omega \\ - i_2\, 8\Omega$$

$$\mathcal{E}_1 - \mathcal{E}_2 = i_2\left(8\Omega + 4\Omega\right) \\ - i_1\, 8\Omega$$

FIGURE 16

KIRCHHOFF'S RULES

TERMINAL OBJECTIVES

13/1 B Answer questions relative to the methods of application of Kirchhoff's Current Law to electrical networks.

13/1 D Apply Kirchhoff's Laws to the solution of numerical problems ranging from simple to more complex multiloop networks.

DEFINITION OF "B" FIELD

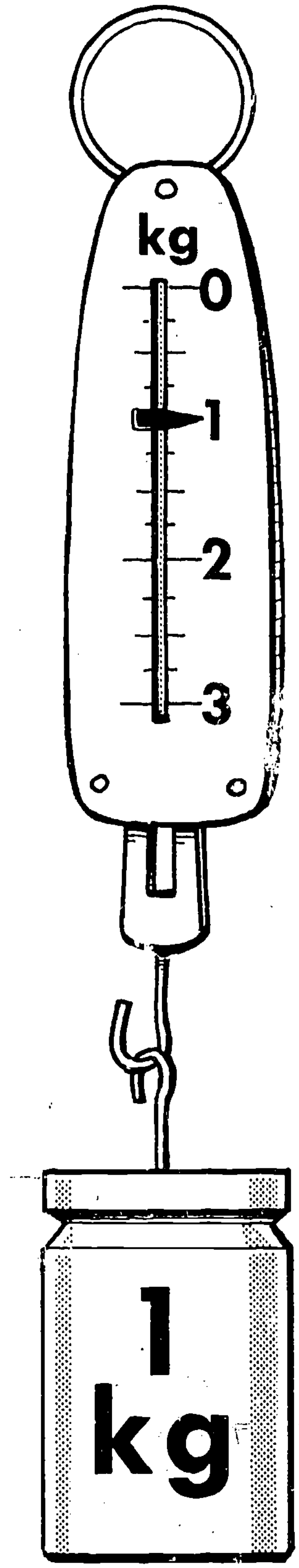


FIGURE 1

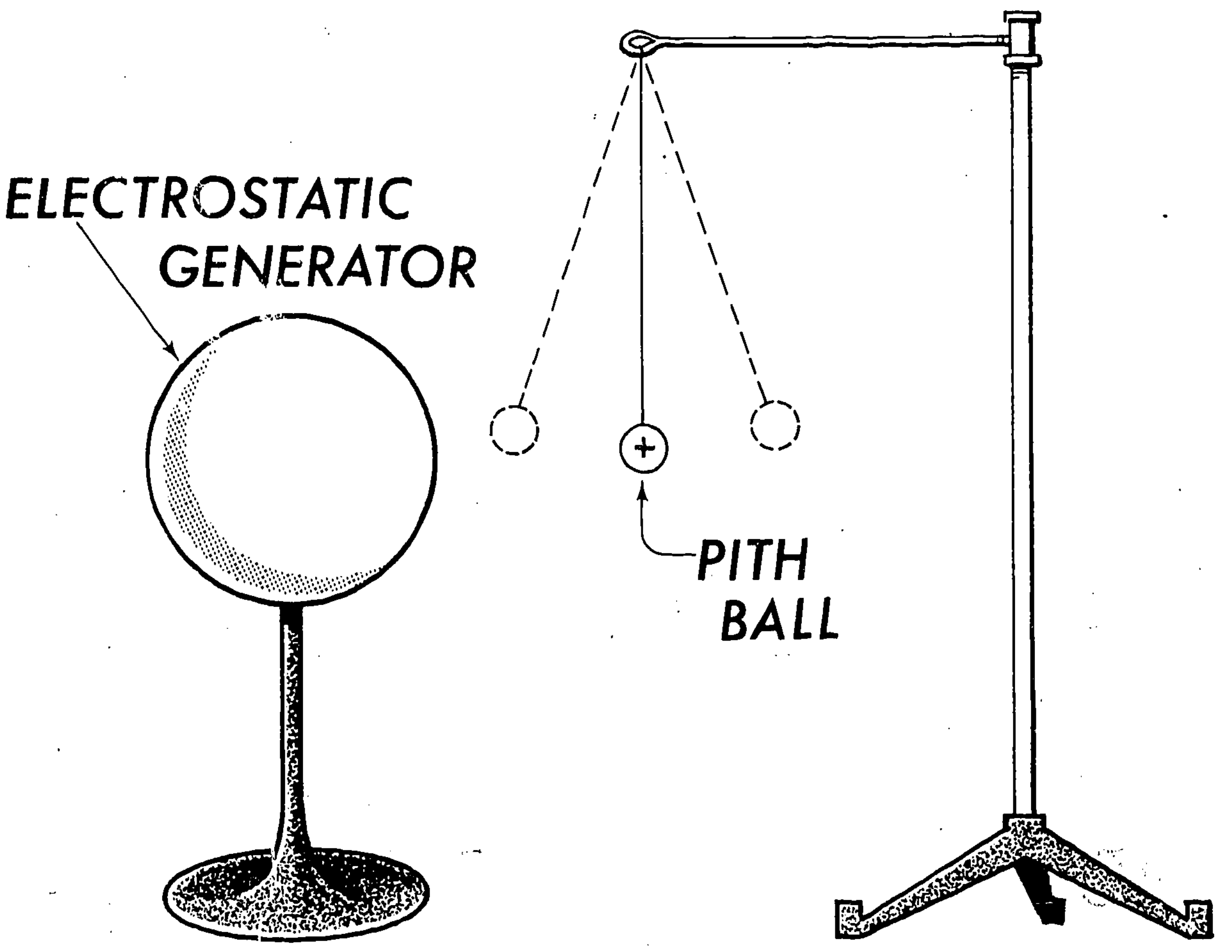


FIGURE 2

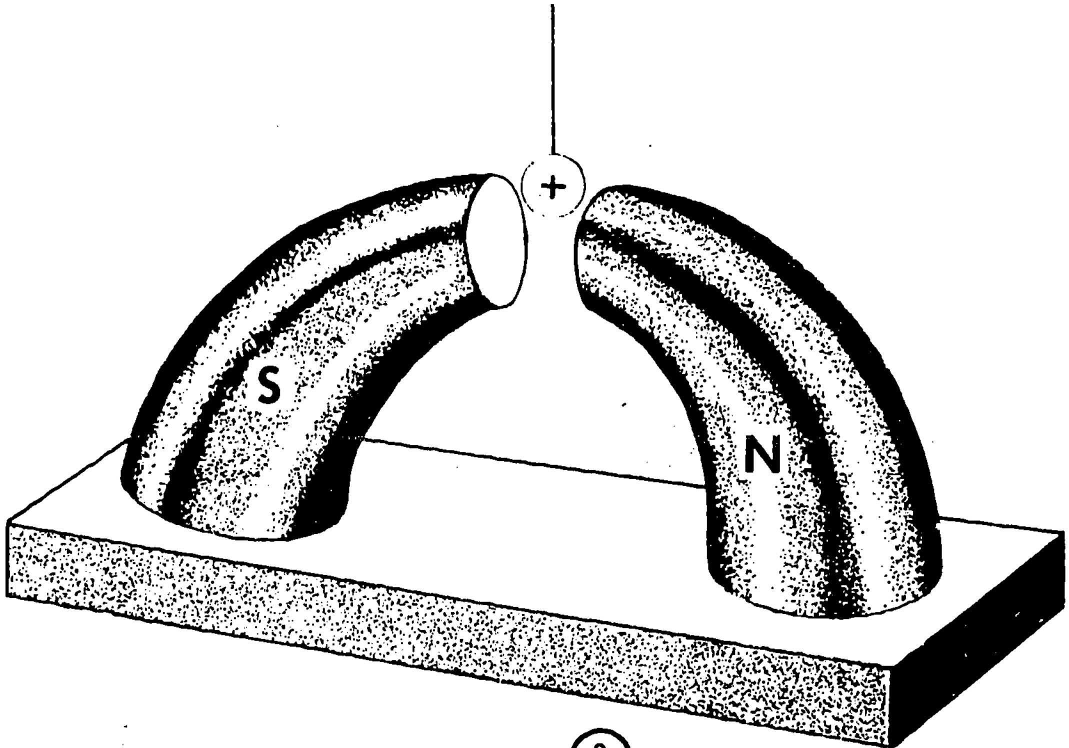


FIGURE 3

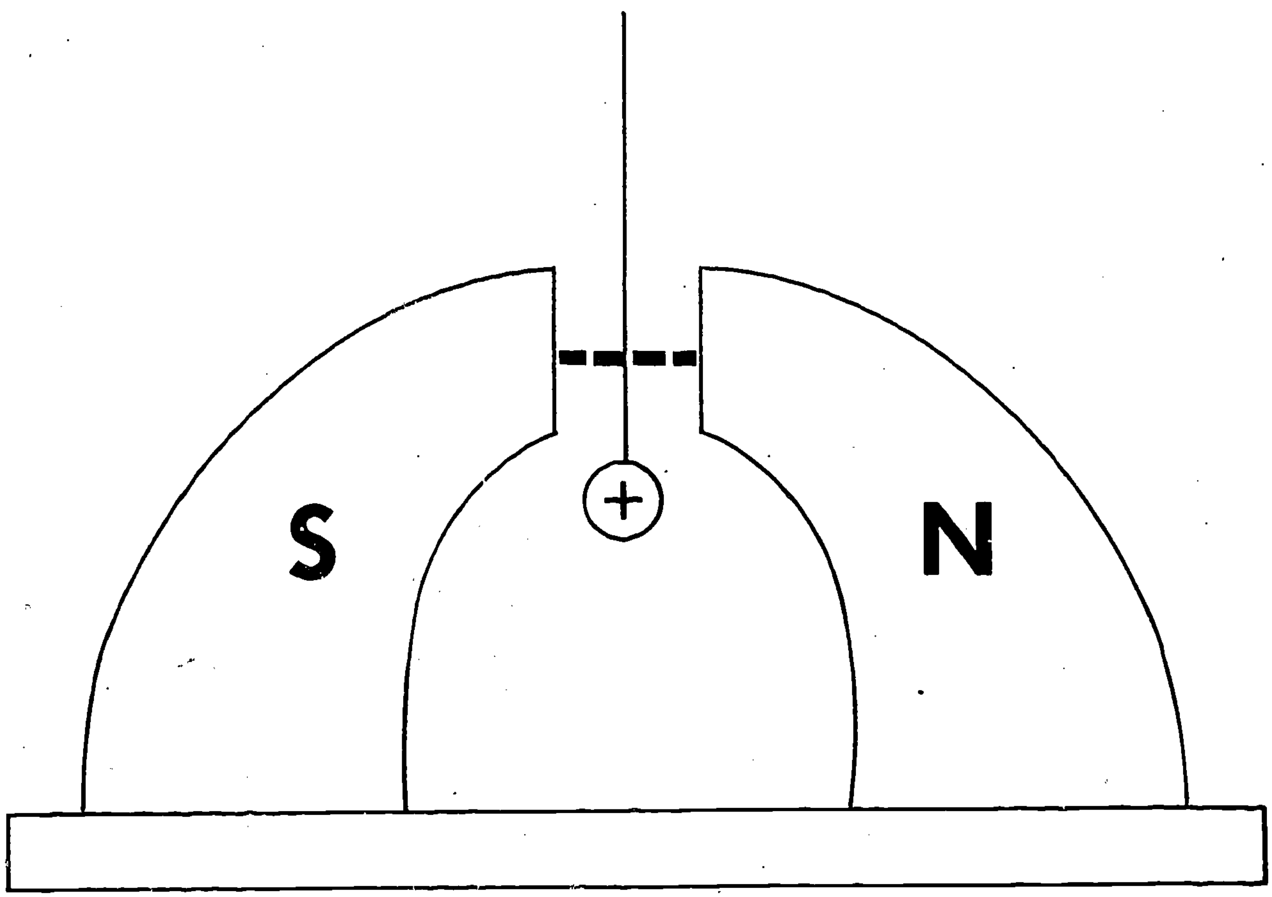


FIGURE 4

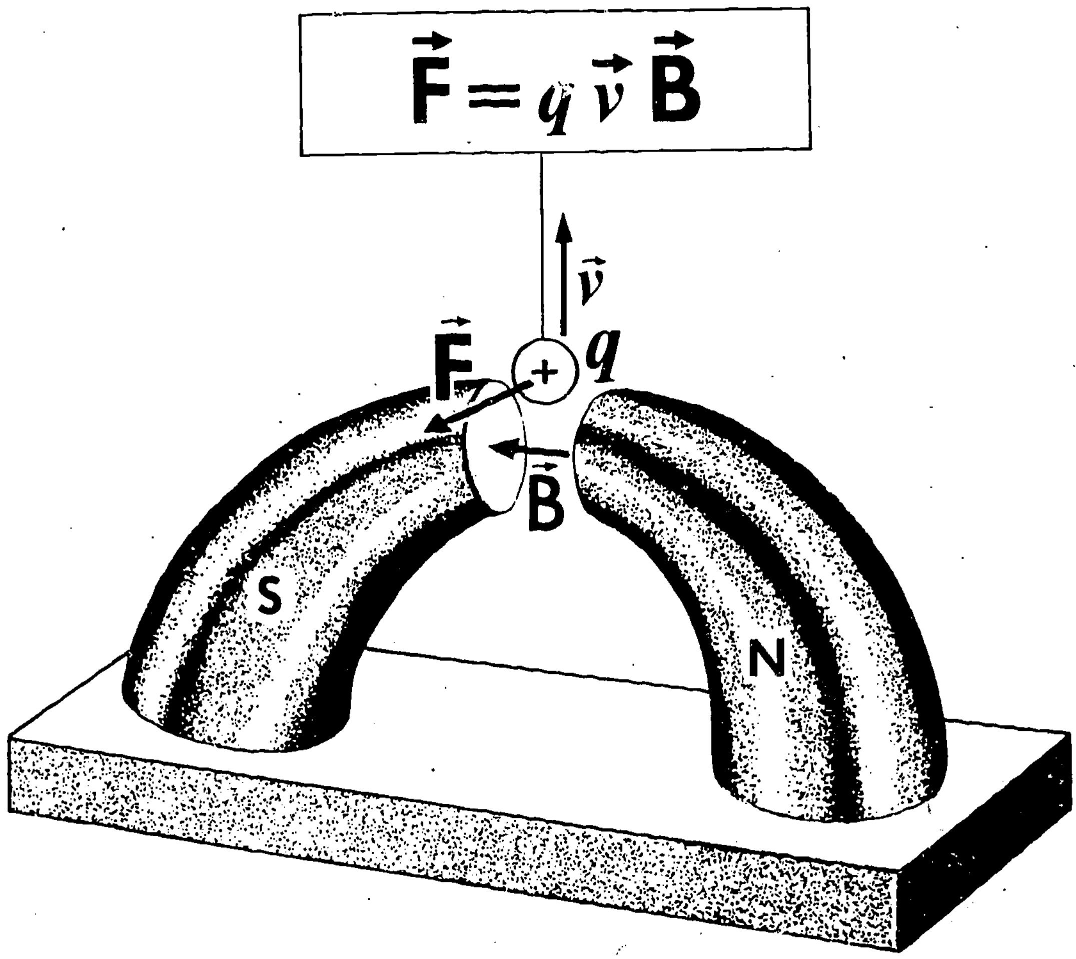


FIGURE 5

CROOKE'S TUBE

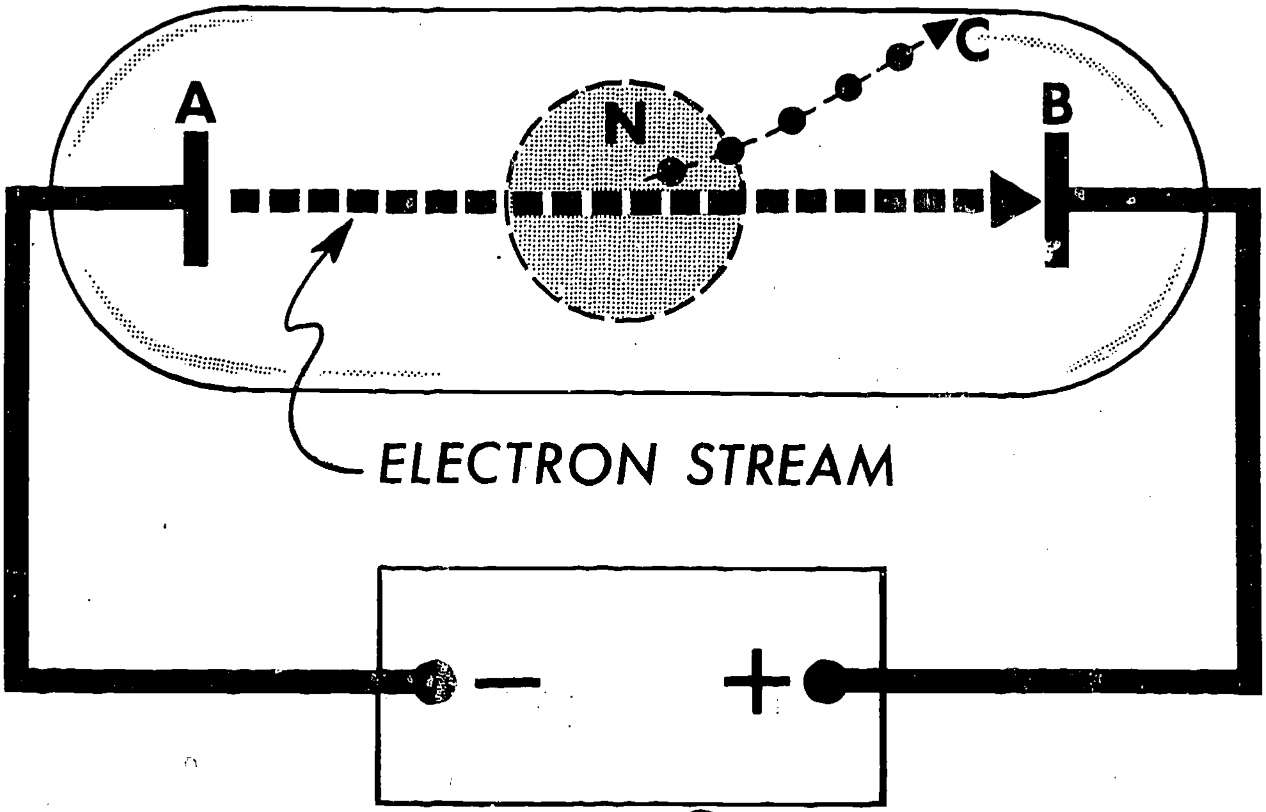


FIGURE 6

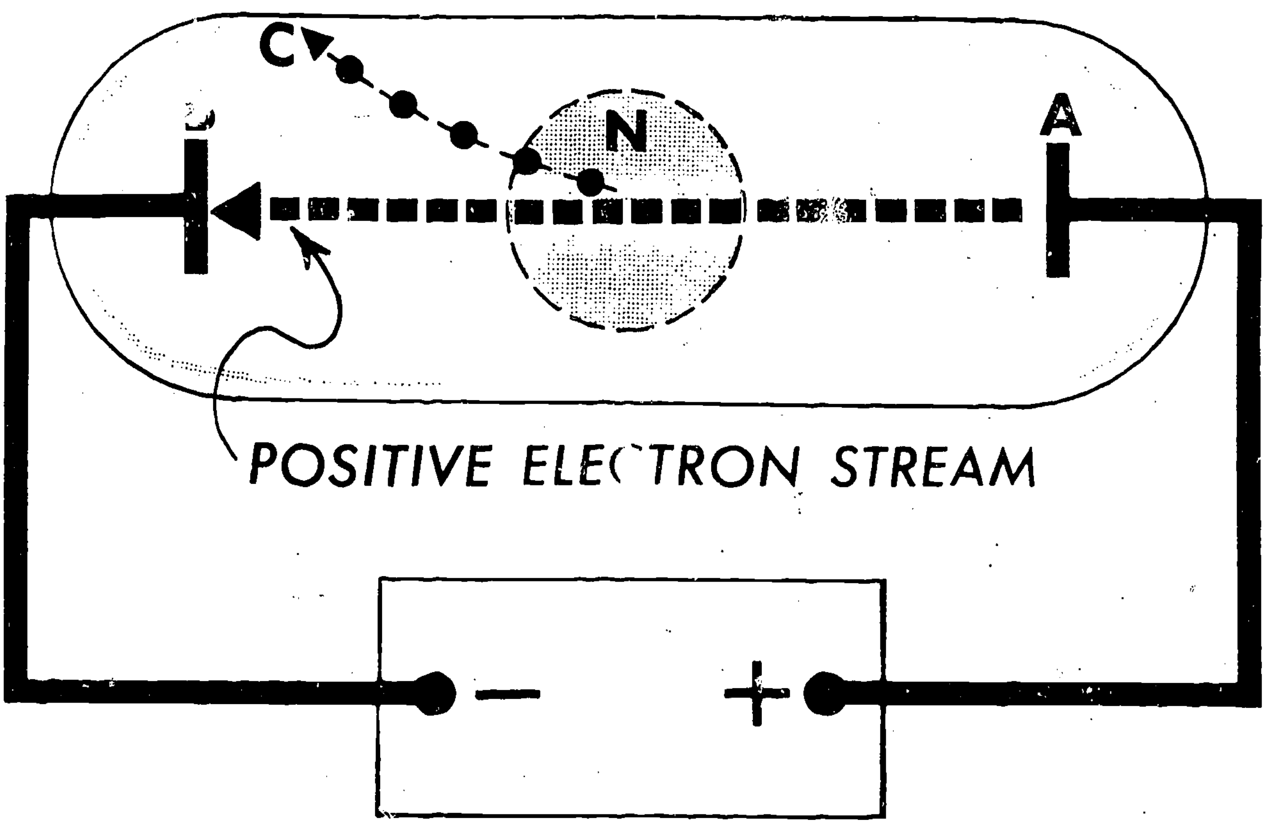


FIGURE 7

$$\vec{F} = q\vec{v} \times \vec{B}$$

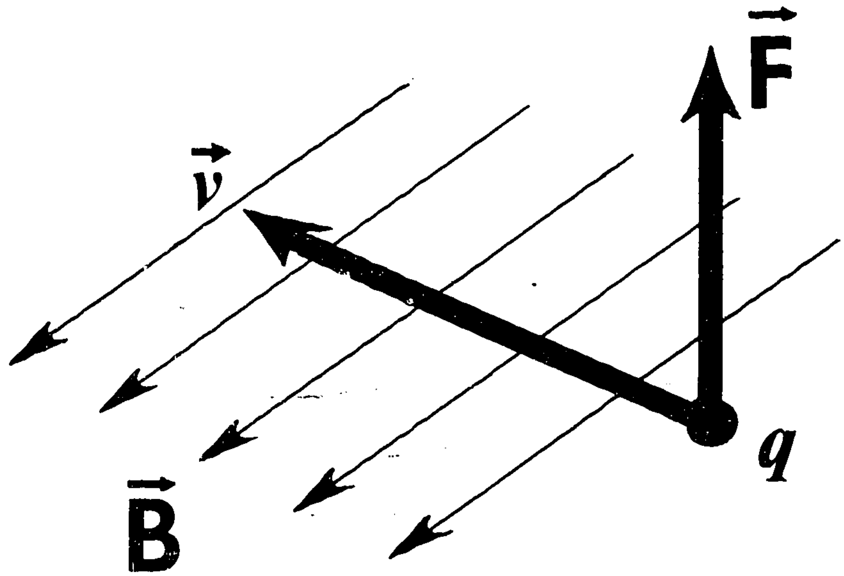


FIGURE 8

UNITS of "B"

(a vector quantity)

$$\frac{nt}{coul\,(m/s)} = \frac{nt}{amp\ m}$$

$$\frac{weber}{m^2} = tesla$$

FIGURE 9

DEFINITION OF "B" FIELD

TERMINAL OBJECTIVES

14/1 B Answer qualitative questions relating to the magnetic induction vector B.

FORCE BETWEEN PARALLEL CURRENT-CARRYING CONDUCTORS

If two wires are freely suspended very close to one another, and if a current is then passed through each of the wires, a force of attraction or repulsion can be detected between them. The direction of the force is a function of the relative current directions; if the current directions are the same in each wire, the conductors will attract one another but if the direction of the current in one of the wires is reversed, the force changes to repulsion. Please refer to Figure 1.

Analysis of the electromagnetic fields that surround each conductor indicates that both the magnitude and the direction of the force can be theoretically predicted. Let us assume that the wires shown in Figure 2 are connected directly to a source of emf, in series with one another, so that the currents are opposite in direction but equal in magnitude.

The current in wire a is directed downward while that in wire b is upward. In order to make the analysis easier to perform in two dimensions, imagine that both wires have been rotated about a horizontal axis so that they present the picture shown in Figure 3. The wires now appear in cross-section as small discs; wire a carries a dot to indicate that the current is directed toward the observer and wire b contains a cross to show that the current in this wire is directed into the plane of the paper, away from the observer. Considering wire a alone for the moment, as in Figure 4, the B-lines surrounding it may be drawn as concentric circles to conform with experimental facts obtained from Oersted's Experiment.

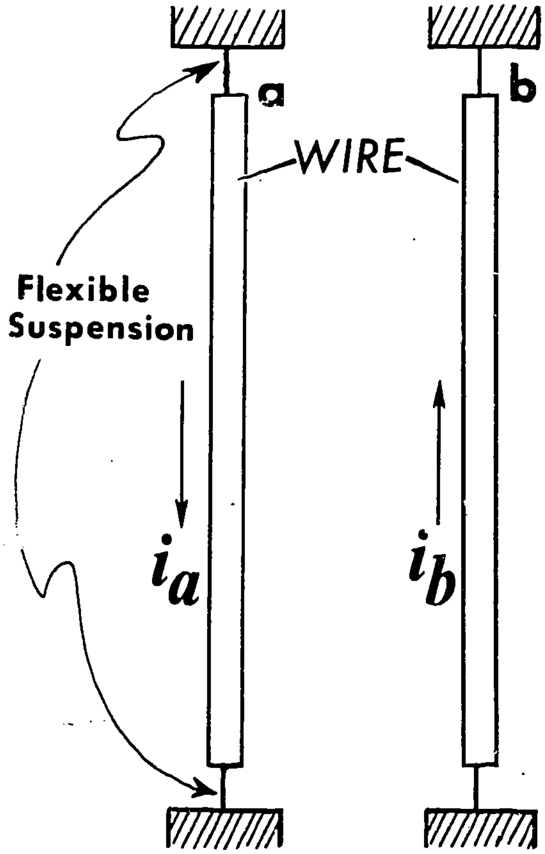


FIGURE 1

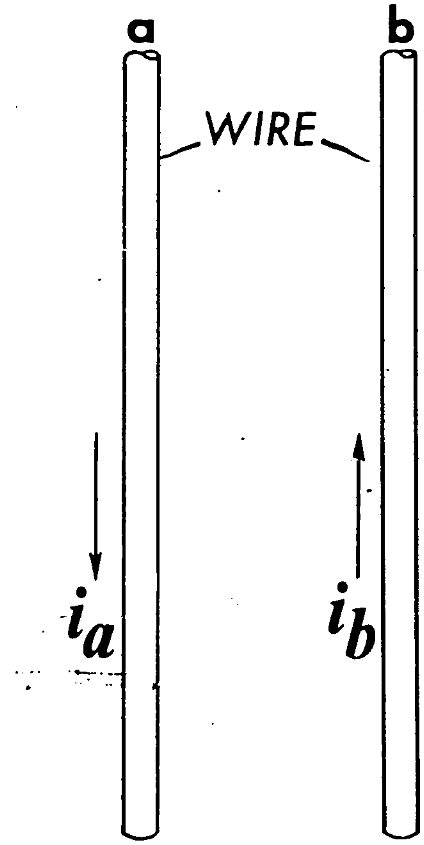


FIGURE 2

FIGURE 3

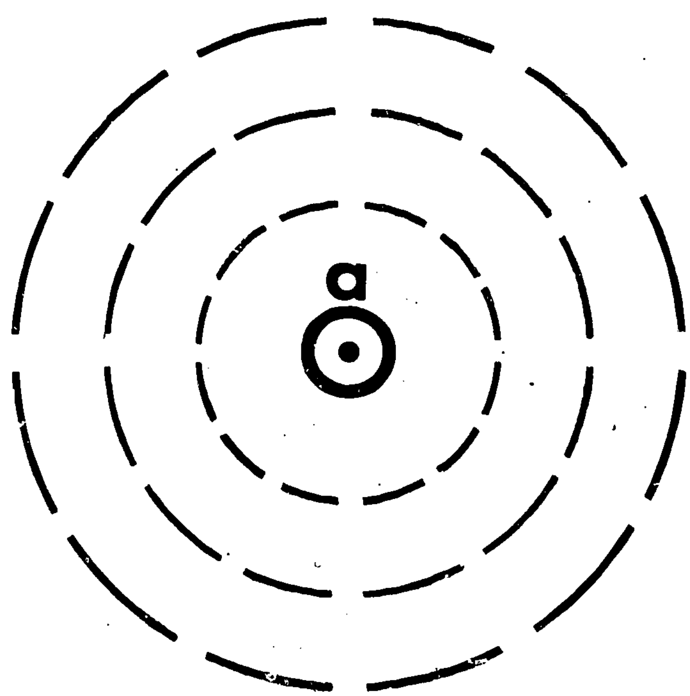


FIGURE 4

Applying the right-hand rule for wires (Oersted's Rule), the thumb of the right hand is pointed in the direction of the conventional current so that the fingers then encircle the wire in the direction of the magnetic field. For this case, the B-lines are counterclockwise in direction as indicated in Figure 5. At a point P near the current-carrying wire, the line of magnetic induction is tangent to the circle of the B-line surrounding the wire.

The magnitude of the field at point P is given by Ampere's Law and may be written as indicated in Figure 6, in which B_p is the magnitude of the field, u_o is the permeability constant, i_a is the current in wire a, and r is the distance between the center of wire a and point P.

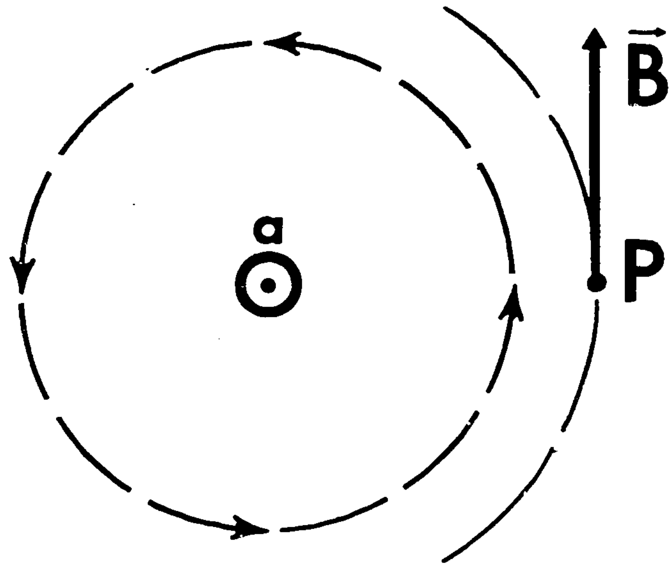
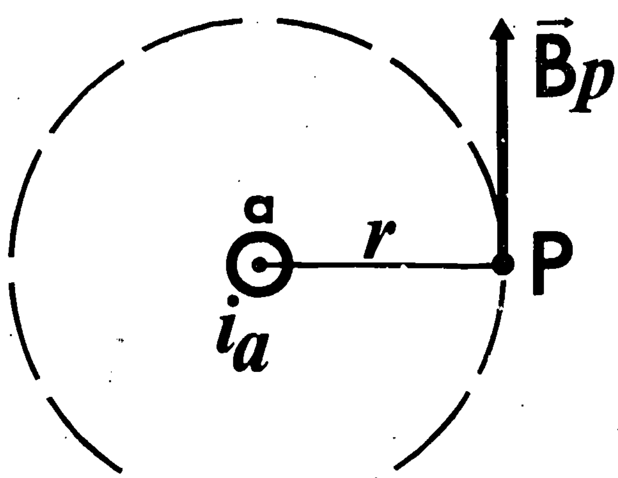


FIGURE 5



$$B_p = \frac{\mu_0 i_a}{2\pi r}$$

FIGURE 6

To review another concept briefly, please refer to Figure 7. In this diagram, a wire is immersed in a magnetic field; the wire carries a current into the plane of the diagram. The source of the magnetic field is not indicated, nor is this information needed to analyze the problem. The B-lines from this unknown source are directed upward in the plane of the paper as indicated. Applying the Palm Rule to determine the direction of the force acting on the current-carrying conductor immersed in the given field, the fingers of the right hand are placed so that they point in the direction of the B-lines while the extended thumb points in the direction of the current. The direction of the force on the wire is then given by the direction in which the palm would exert a thrust if the hand were used in the normal manner. In the example given in Figure 5, the direction of the force would be that shown in Figure 8, namely to the right as viewed by the observer.

The Palm Rule may always be used in this way and will be found to be a great help in analyzing this kind of situation and others similar to it.

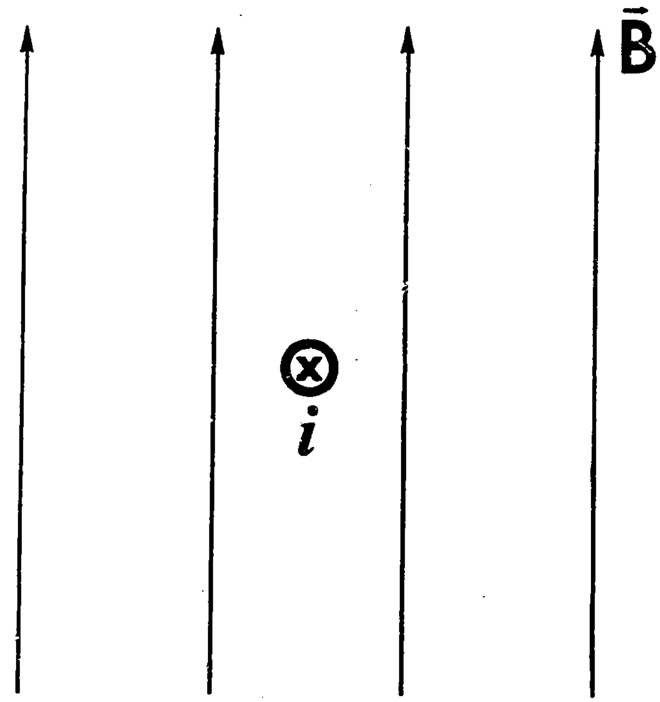


FIGURE 7

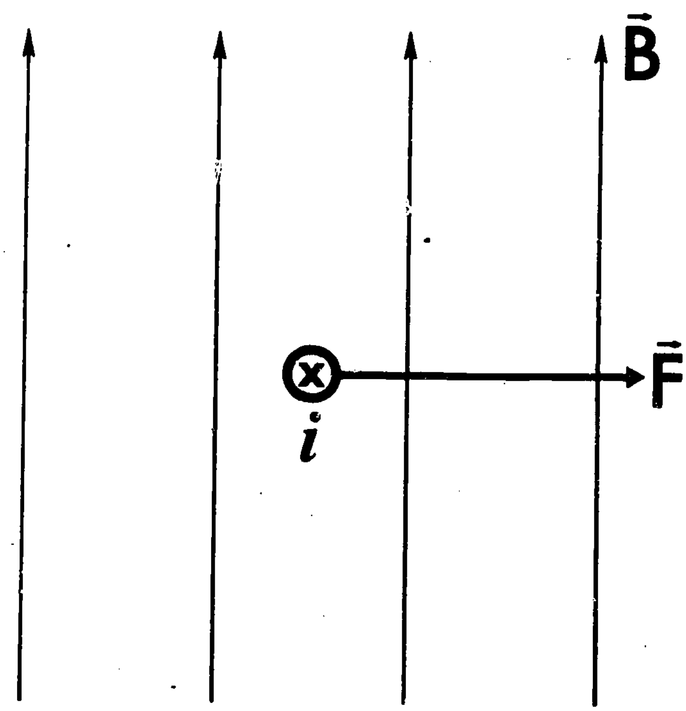


FIGURE 8

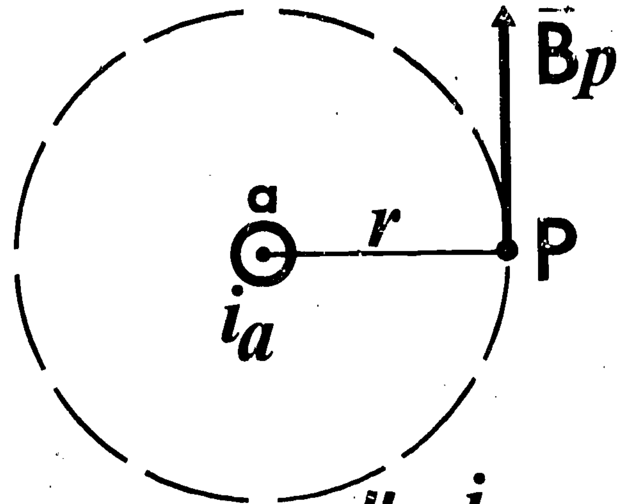
The magnitude of the force on the current-carrying wire is given by the relation shown in Figure 9. Thus, both the magnitude of the force and its direction are determinable for the example given. Please refer to Figure 10; this is reiteration for review. Also refer to Figure 11.

These ideas may now be combined to determine the nature of the force in a specific case; that is, to determine whether to expect attraction or repulsion when the current directions are known. Working with conductors carrying oppositely directed currents as in Figure 12, it can be readily shown that the force is one of repulsion in the following manner.

The line of magnetic induction at wire b due to the current in wire a is labeled B_a. Applying the Palm Rule to wire b, it is seen that the force on this wire is directed to the right away from wire a as illustrated in Figure 13. The magnitude of the force is given in the same Figure. In this relationship, F_b is the force acting on wire b, i_b is the current in wire b, l_b is the length of wire b, and B_a is the magnetic induction due to the current in wire a.

$$F = il\,B_{\perp}$$

FIGURE 9



$$Bp = \frac{\mu_0\, i_a}{2\pi r}$$

FIGURE 10

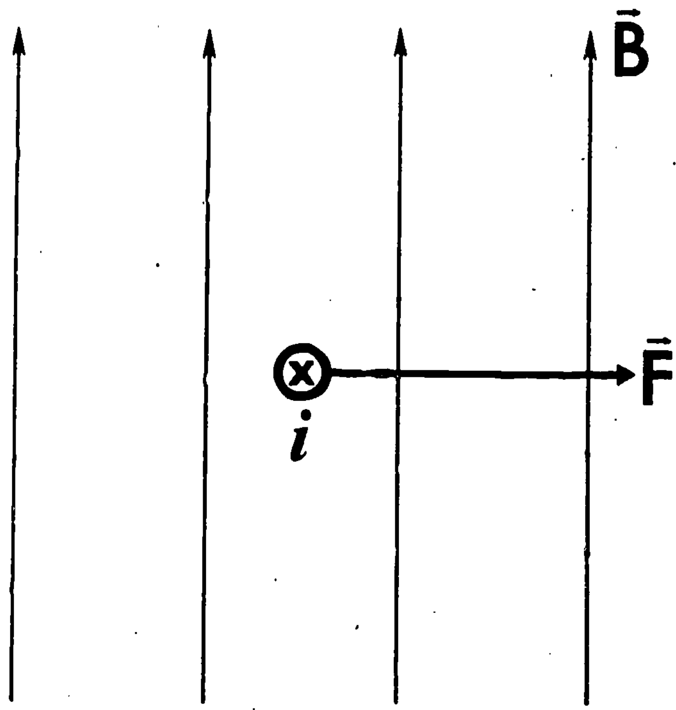


FIGURE 11

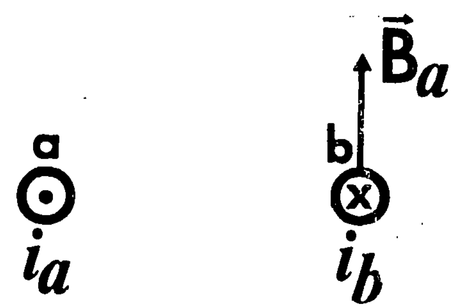


FIGURE 12

$$\boxed{F_b = i_b\ l_b\ B_a}$$

FIGURE 13

Exactly the same process may be followed to find the force acting on wire a due to the current in wire a and the magnetic induction produced by the current in wire b. The right-hand rule is first applied to wire b; this demonstrates that the B-line at wire a is directed upward. Then the Palm Rule is applied to wire a, showing that the force on this wire acts to the left away from wire b. The direction and magnitude of this force is diagrammed in Figure 14. The student should confirm this for himself.

Thus, the wires repel each other. From Third Law considerations alone, one may conclude that the force on wire a must equal the force on wire b since they form an action-reaction pair. The fact that the forces are equal may also be shown directly as in Figure 15. In the first step, the magnitude of F_b is given in equation form. In the second step, B_a has been replaced by its equivalent, i.e., $\mu_o i_a/2\pi r$. Both sides are then divided by the wire length to yield the force per unit length in the third step. The remainder is self-explanatory.

$$\boxed{F_a = i_a\, l_a\, B_b} \qquad \boxed{F_b = i_b\, l_b\, B_a}$$

FIGURE 14

$$F_b = i_b\, l_b \underbrace{\frac{\mu_o\, i_a}{2\pi r}}_{B_a}$$

$$\frac{F_b}{l_b} = \frac{\mu_o\, i_b\, i_a}{2\pi r}$$

and assuming equal lengths and currents

$$\frac{F}{l} = \frac{\mu_o\, i^2}{2\pi r} \text{ for either wire}$$

FIGURE 15

In summary, as presented in Figure 16, the force between current-carrying wires is one of REPULSION if the currents are OPPOSITELY DIRECTED; the force is ATTRACTION if the currents have the SAME DIRECTION. The force per unit length on either wire for equal currents and equal lengths is given by

$$F/l = \mu_o i^2 / 2\pi r$$

Summary

REPULSION, if currents are oppositely directed;

ATTRACTION, if currents have same direction.

$$\frac{F}{l} = \frac{\mu_0 \, i^2}{2\pi r}$$

for either wire if currents are equal.

FIGURE 16

FORCE BETWEEN PARALLEL CURRENT-CARRYING CONDUCTORS

TERMINAL OBJECTIVES

14/3 A Describe the magnetic field around a straight-current-carrying conductor.

14/3 D Prove that the force between wires a and b in the diagram is an attractive force, the magnitude of the force on either wire being given by (equation).

AMPERE'S LAW APPLIED TO A LONG STRAIGHT CONDUCTOR

AMPERE'S LAW

$$\oint \vec{B} \cdot d\vec{l} = \mu_0 i$$

FIGURE 1

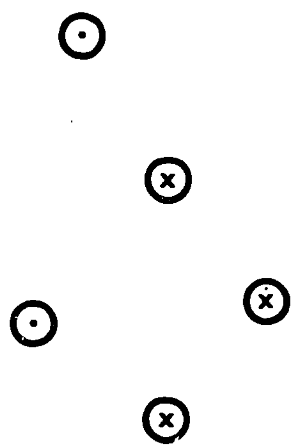


FIGURE 2

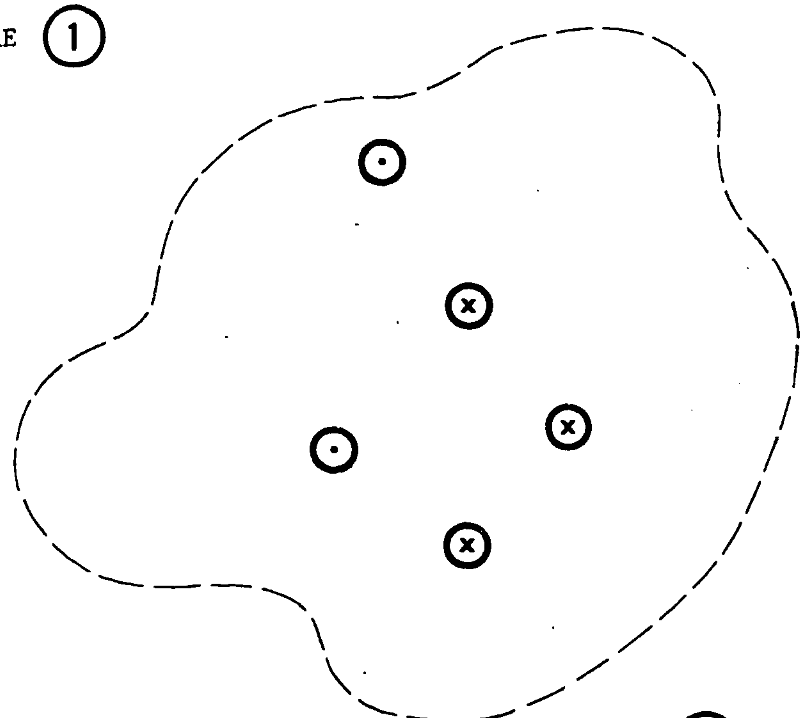


FIGURE 3

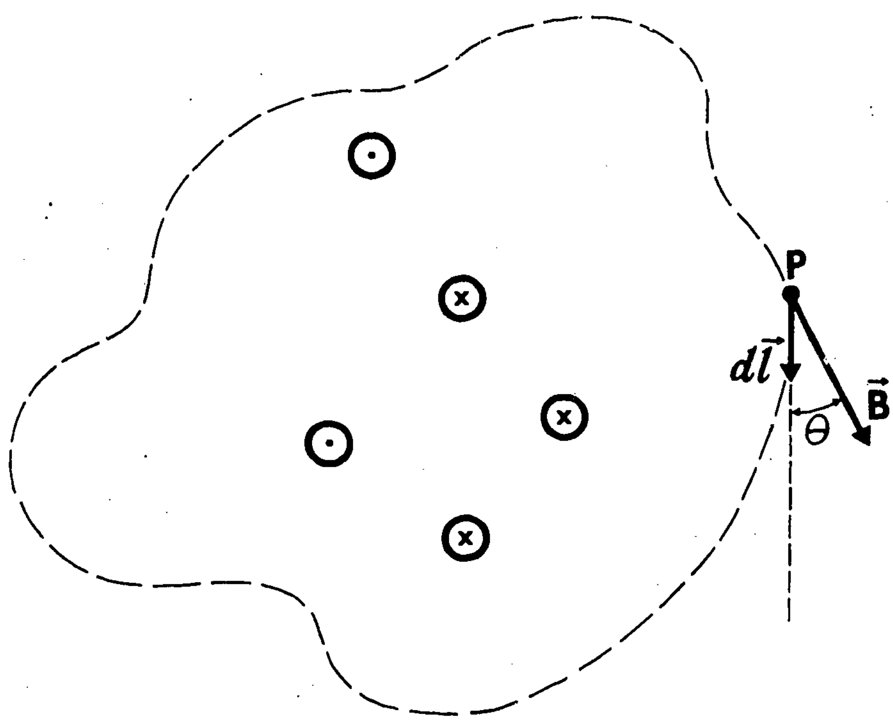


FIGURE 4

$$\oint \vec{\mathbf{B}} \cdot d\vec{l} = \mu_0 i$$

where $\mu_0 = 4\pi \ (10^{-7})$

$web / amp \cdot m$

and

$$\vec{\mathbf{B}} \cdot d\vec{l} = B\, d\vec{l} \cos \theta$$

FIGURE 5

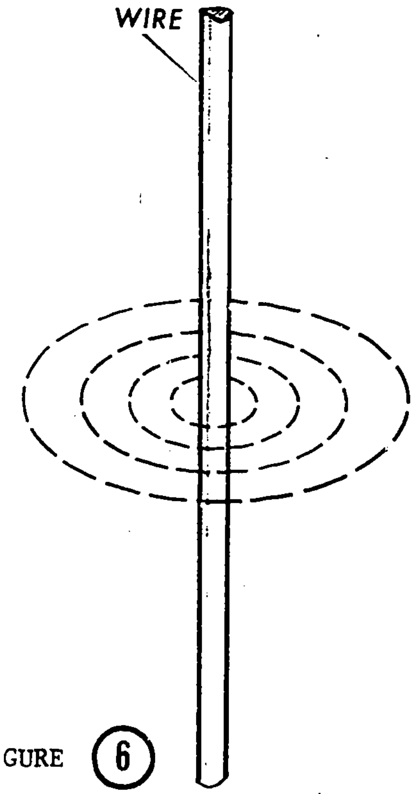


FIGURE (6)

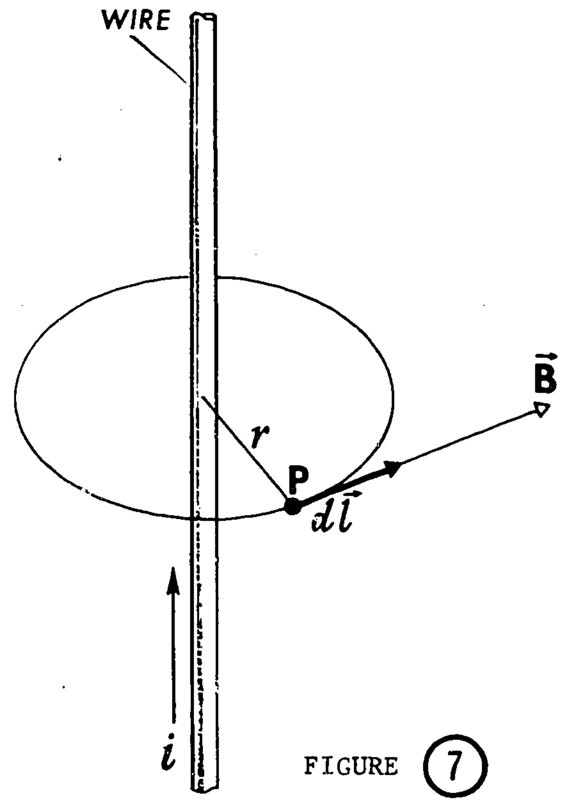


FIGURE (7)

AMPERE'S LAW

$$\oint \vec{B} \cdot d\vec{l} = \mu_0 i$$

FIGURE (8)

FIGURE (9a) $\oint \vec{B} \cdot d\vec{l} = \oint B \, dl \cos \Theta$

" (9b) $\oint B \, dl \cos \Theta = \oint B \, dl$

" (9c) $\oint B \, dl = B \oint dl$

" (9d) $B\left(2\pi r\right) = \mu_0 i$ or $B = \dfrac{\mu_0 i}{2\pi r}$

FIGURE (10) $B\left(\dfrac{web}{m^2}\right) = \dfrac{2i(amp)}{r\ (m)} \times 10^{-7} \dfrac{web}{amp \cdot m}$

AMPERE'S LAW APPLIED TO A LONG STRAIGHT CONDUCTOR

TERMINAL OBJECTIVES

14/3 A Describe the magnetic field around a straight-current- carrying conductor.

14/3 F Answer questions and solve problems involving Ampere's law and its applications.

THE LAW OF BIOT-SAVART

T

AMPERE'S LAW

$$\oint \vec{B} \cdot d\vec{l} = \mu_0 i$$

FIGURE 1

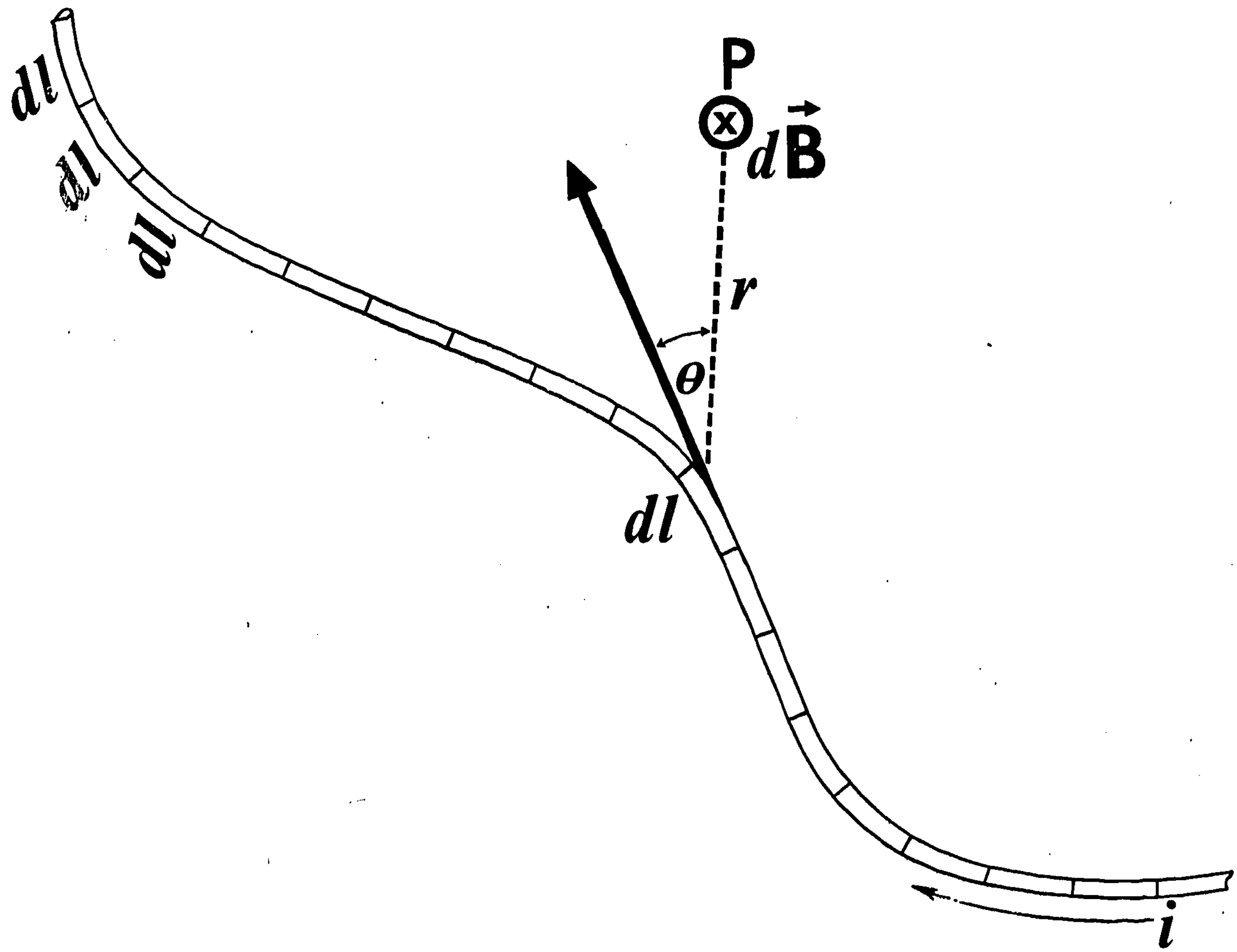
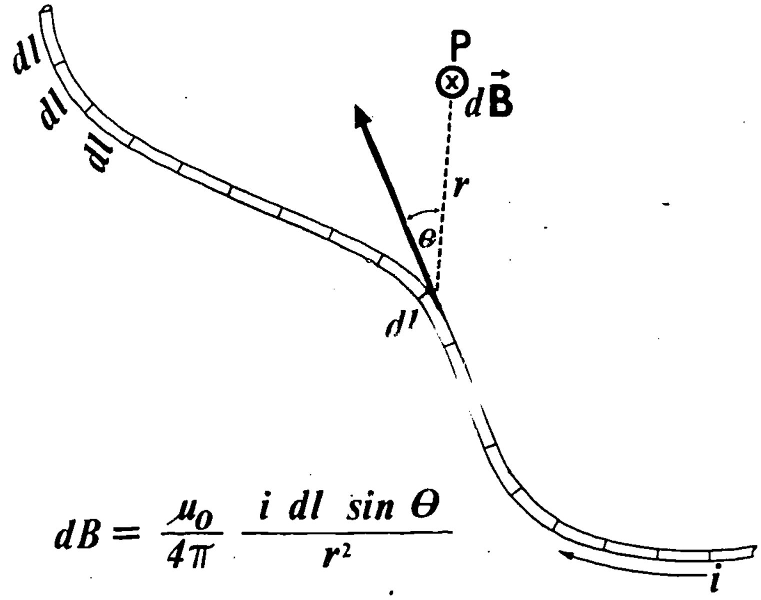


FIGURE 2



$$dB = \frac{\mu_0}{4\pi} \frac{i\, dl\, \sin\theta}{r^2}$$

FIGURE (3)

$$\vec{B}_p = \int d\vec{B}$$

FIGURE (4)

$$= \int \frac{\mu_0}{4\pi} \frac{i\, dl\, \sin\theta}{r^2}$$

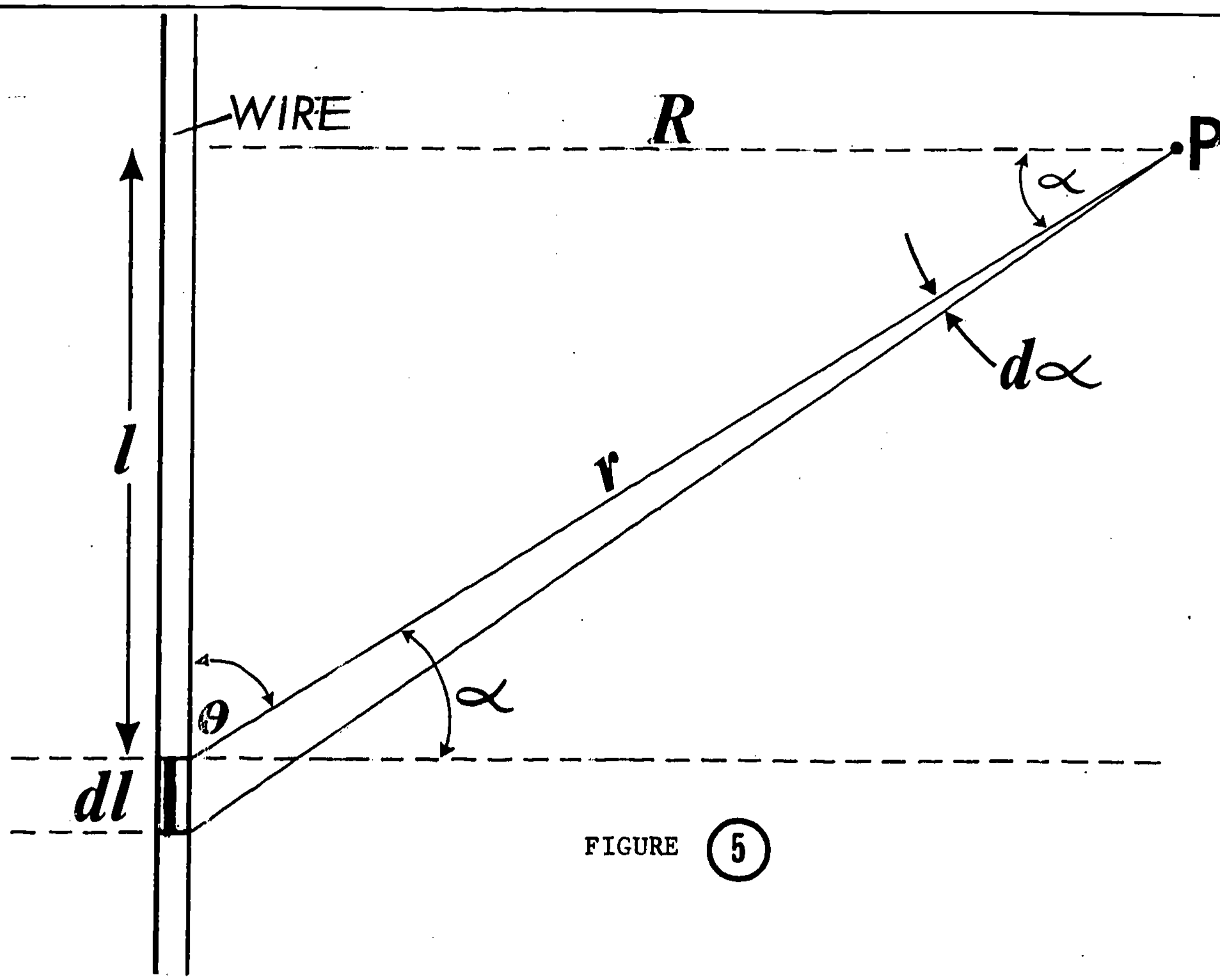


FIGURE (5)

$$B = \int \frac{\mu_0}{4\pi} \frac{i \; dl \; \sin \Theta}{r^2}$$

$$B = \int \frac{\mu_0}{4\pi} \frac{i \; dl \; \cos \alpha}{r^2}$$

FIGURE 6

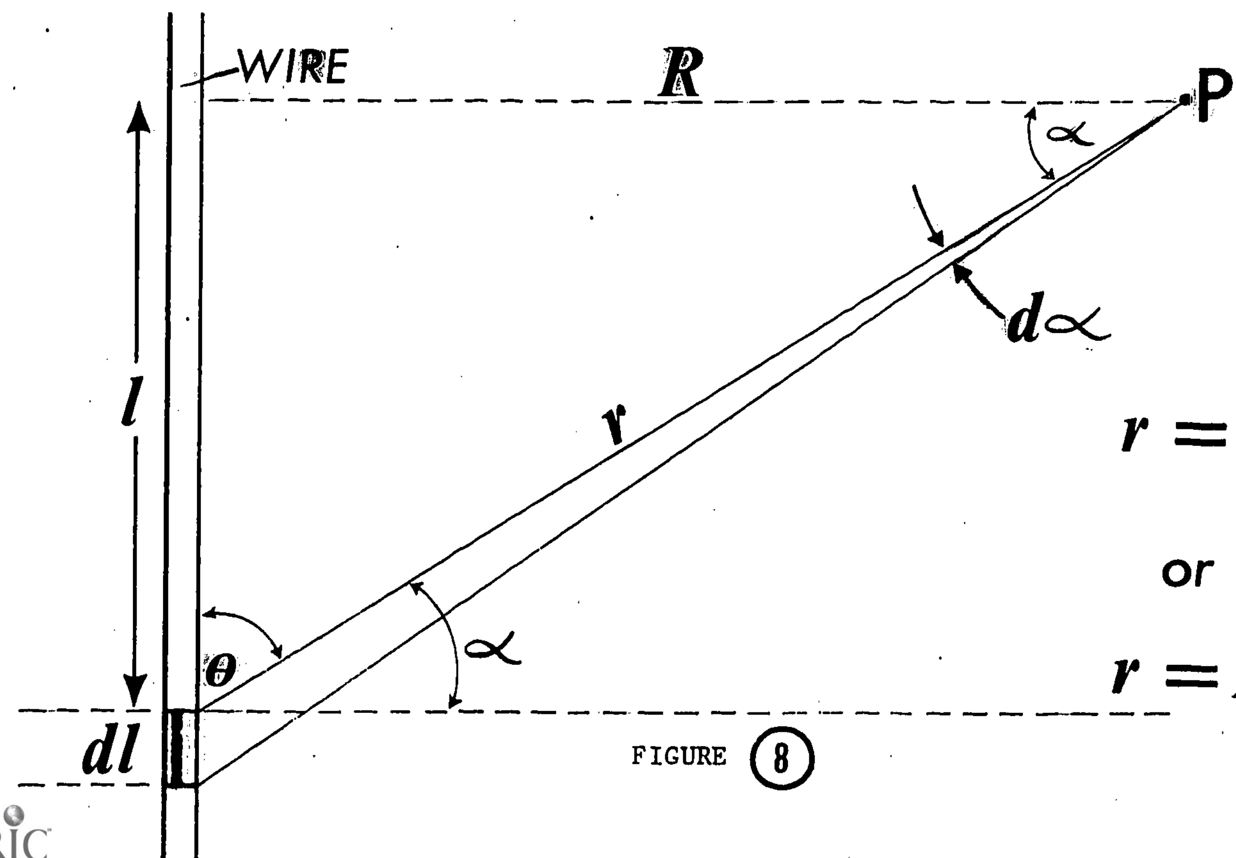
$$B = \int \frac{\mu_0}{4\pi} \frac{i \; dl \; \cos \alpha}{r^2}$$

$$l = R \tan \alpha$$

$$\frac{dl}{d\alpha} = R \sec^2 \alpha$$

or $dl = R \sec^2 \alpha \, d\alpha$

FIGURE 7



$$r = \frac{R}{\cos \alpha}$$

or better

$$r = R \sec \alpha$$

FIGURE 8

(a) $$dB = \frac{\mu_0 i}{4\pi} \frac{R \sec^2 \alpha \cos \alpha \, d\alpha}{r^2}$$

(b) $$dB = \frac{\mu_0 i}{4\pi} \frac{R \sec^2 \alpha \cos \alpha \, d\alpha}{R^2 \sec^2 \alpha}$$

(c) $$dB = \frac{\mu_0 i}{4\pi} \frac{\cos \alpha \, d\alpha}{R}$$

(d) $$B = \int_{-\frac{\pi}{2}}^{\frac{\pi}{2}} dB = \frac{\mu_0 i_0}{4\pi R} \int_{-\frac{\pi}{2}}^{\frac{\pi}{2}} \cos \alpha \, d\alpha$$

FIGURE 9

(a) $$B = \frac{\mu_0 i}{4\pi R} \int_{-\frac{\pi}{2}}^{\frac{\pi}{2}} \cos \alpha \, d\alpha$$

becomes

(b) $$B = \frac{\mu_0 i}{4\pi R} \Big[\sin \alpha \Big]_{-\frac{\pi}{2}}^{\frac{\pi}{2}} = \frac{\mu_0 i}{4\pi R} \Big[1 - (-1) \Big]$$

(c) $$B = \frac{\mu_0 i}{2\pi R}$$

FIGURE 10

THE LAW OF BIOT-SAVART

TERMINAL OBJECTIVES

15/1 A Derive the expression for the magnetic induction within an ideal solenoid as (equation) is the actural current in the solenoid ~~wire~~ and n is the number of turns. (diagram)

15/1 D Use Fig. 4 as an aid in mathematically deriving the equation for the magnetic induction at point P; (equation).

T

FARADAY'S LAW OF INDUCTION

$$d\phi = B_n\, dA \quad \vec{\mathbf{B}} \cdot d\vec{\mathbf{A}}$$

$$\phi = \int \vec{\mathbf{B}} \cdot d\vec{\mathbf{A}}$$

FIGURE 1

$$\phi = \int B \cos \theta \, dA$$

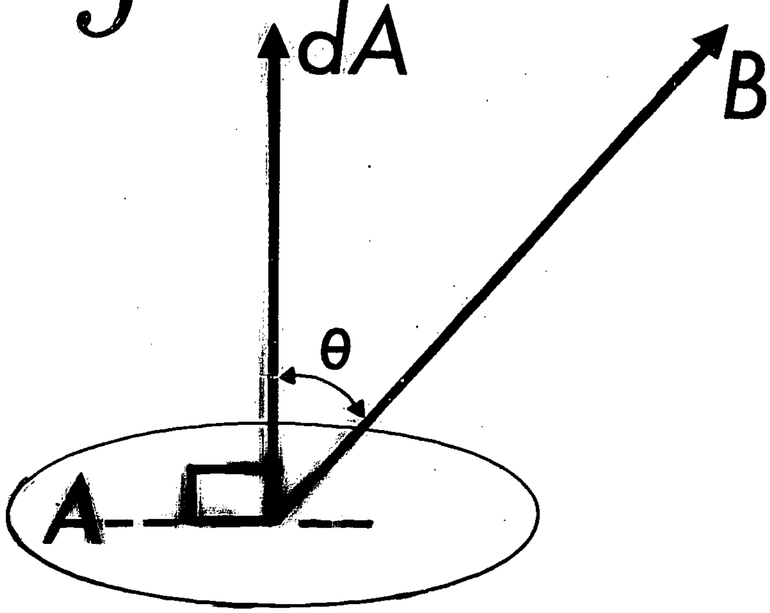


FIGURE 2

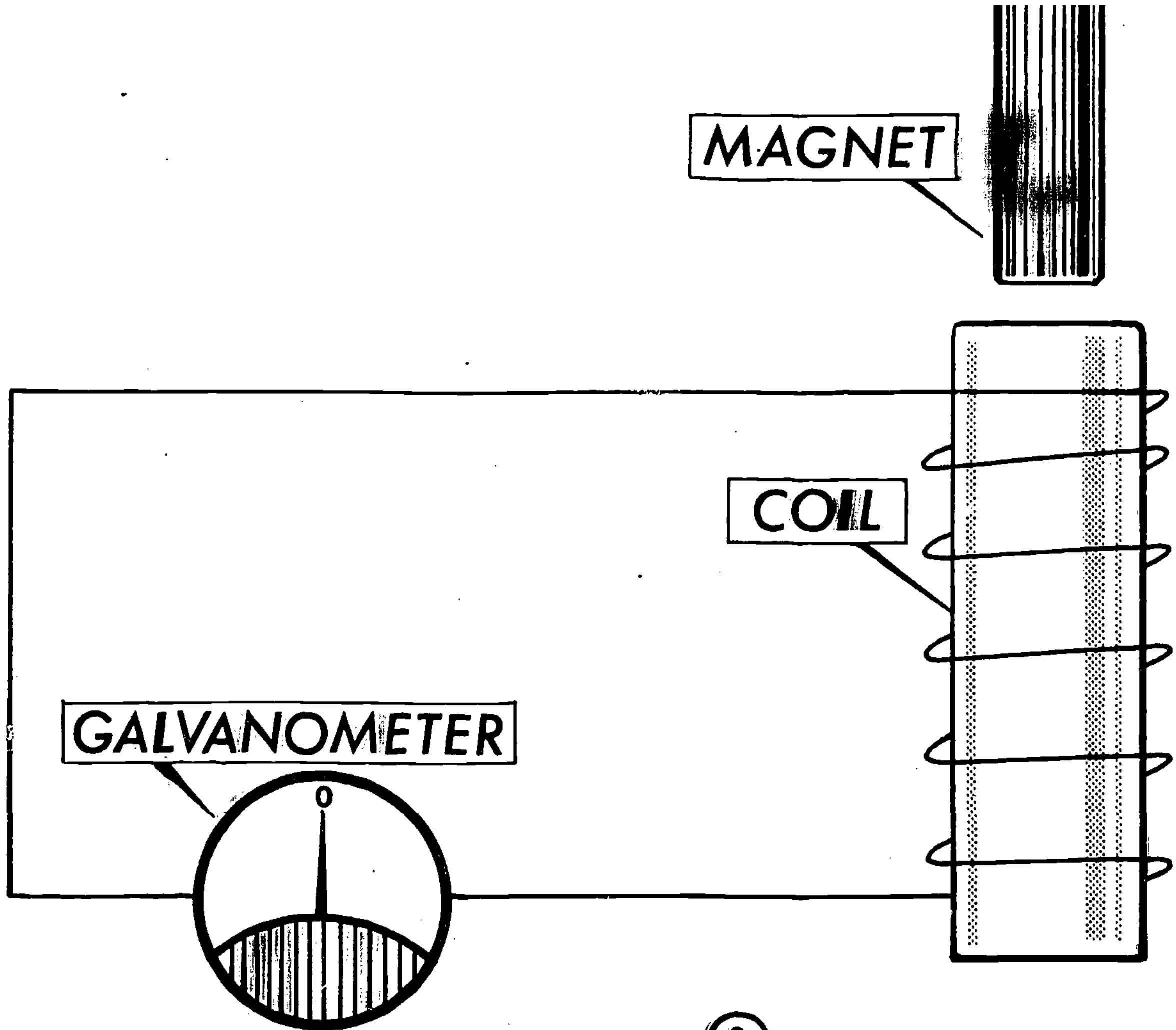


FIGURE 3

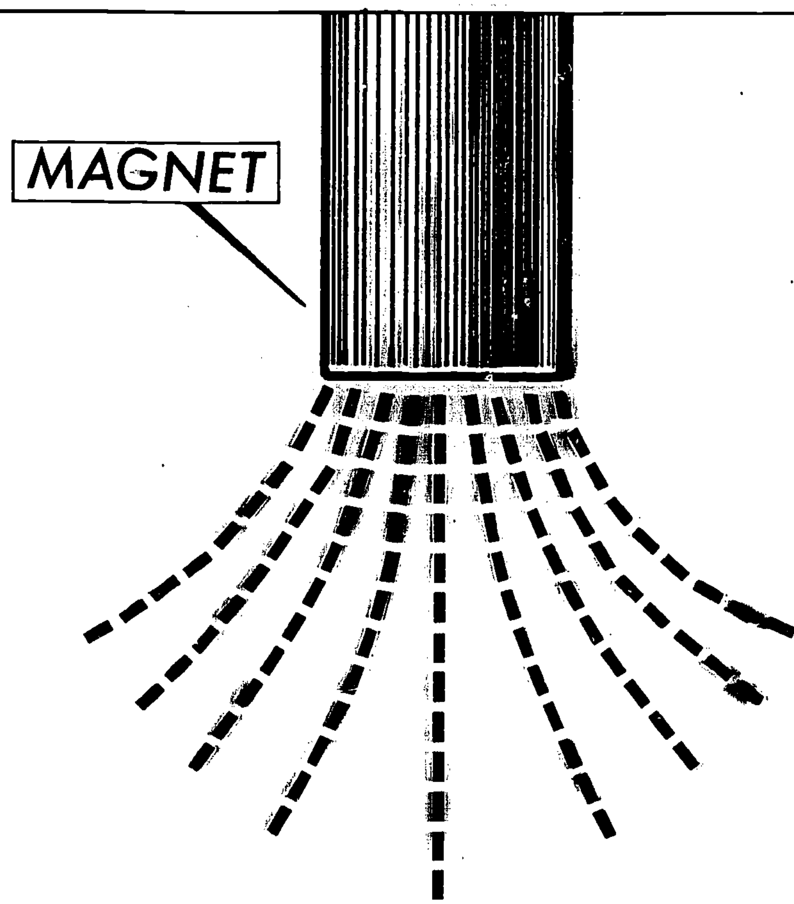


FIGURE 4

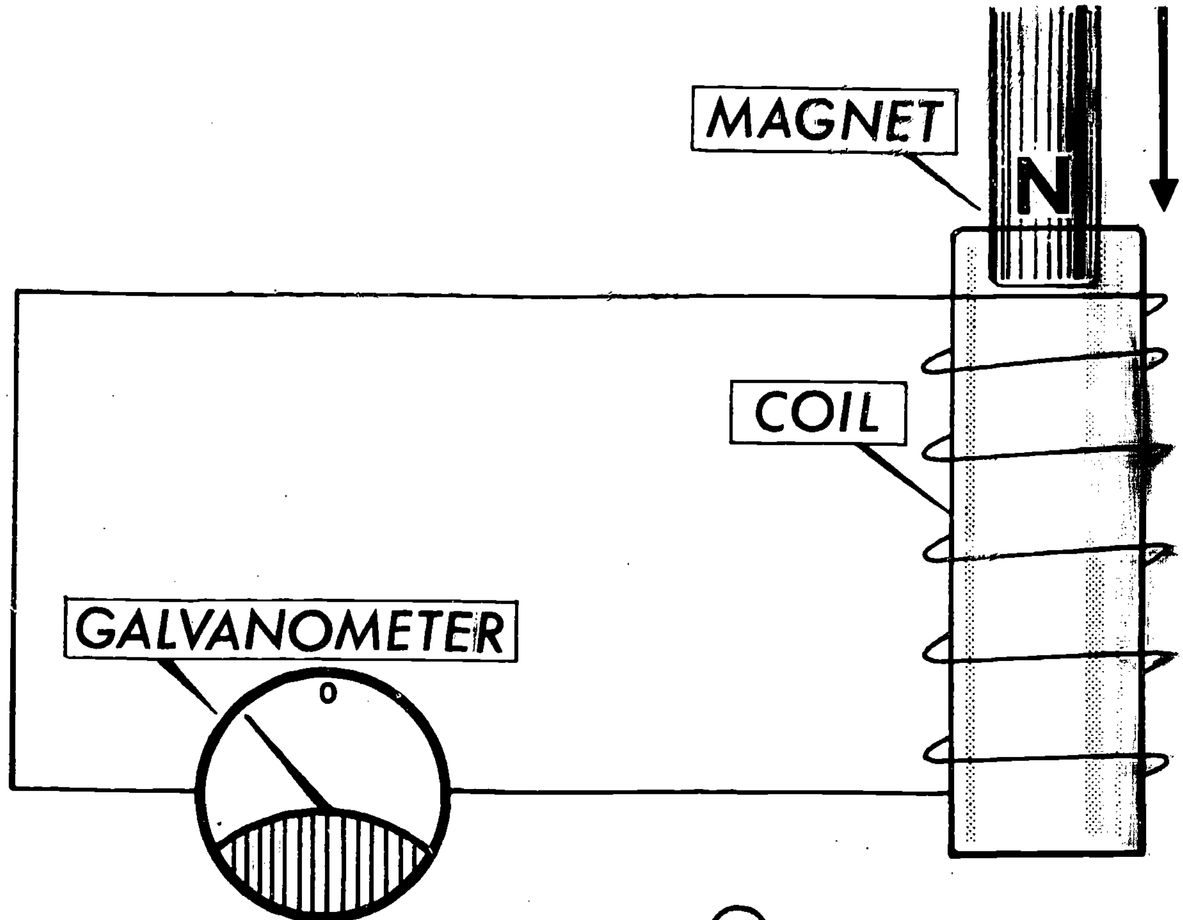


FIGURE 5

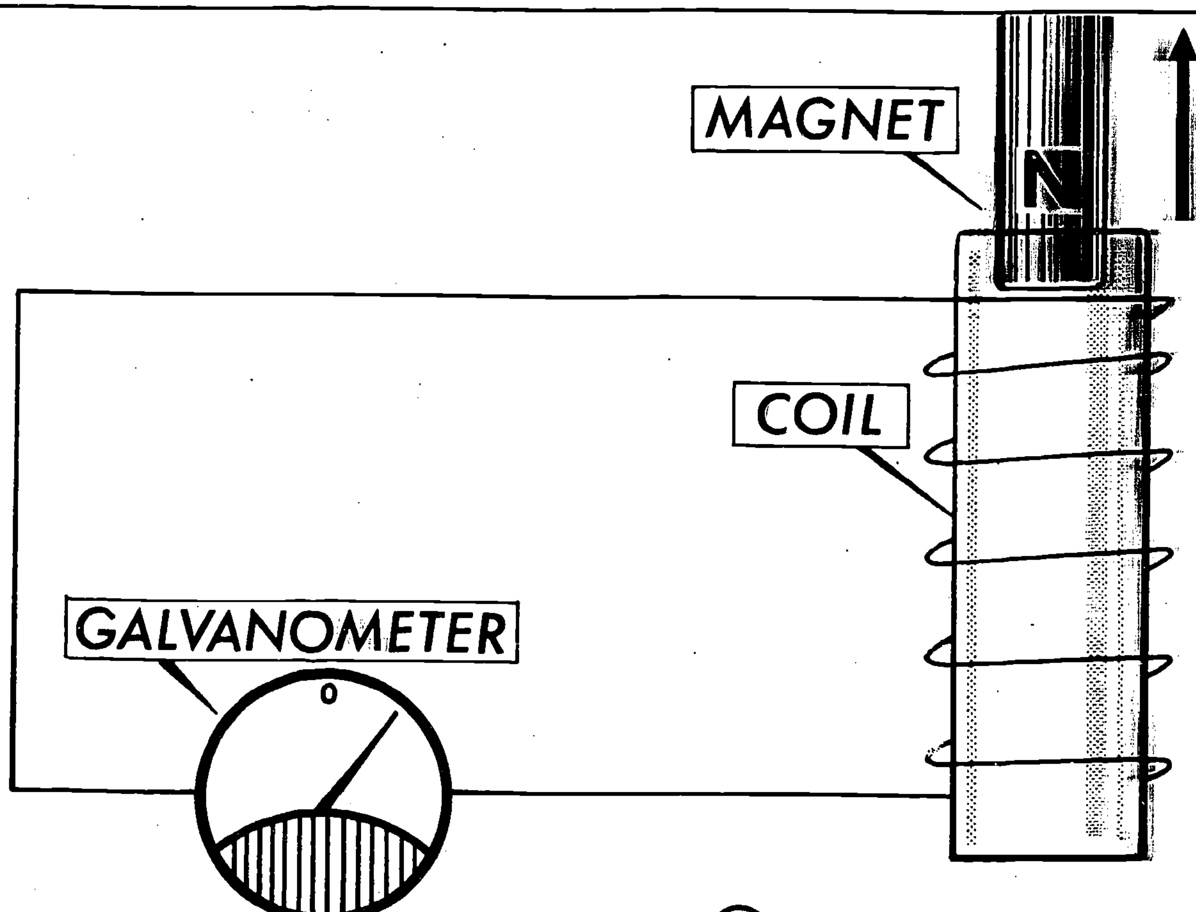


FIGURE 6

$$\mathcal{E} \propto \frac{d\Phi}{dt}$$

FIGURE 7

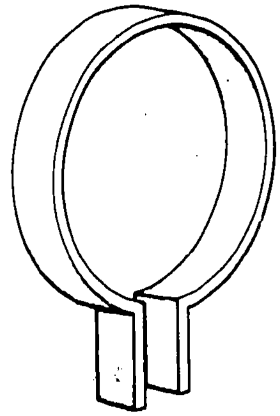


FIGURE 8

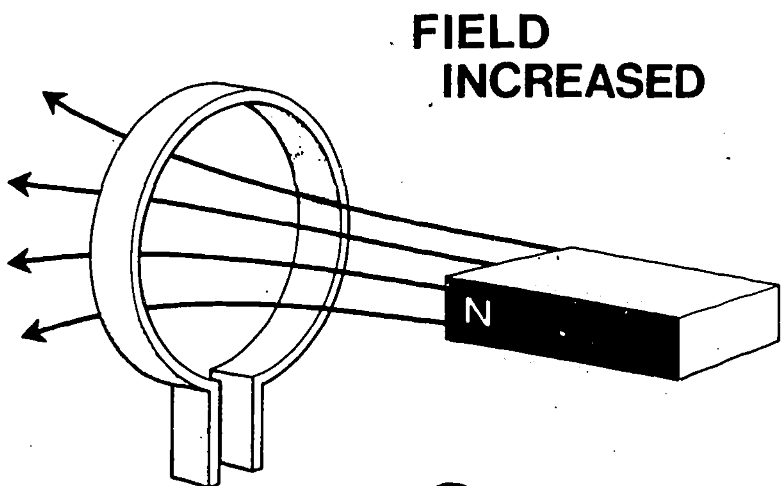


FIGURE 9

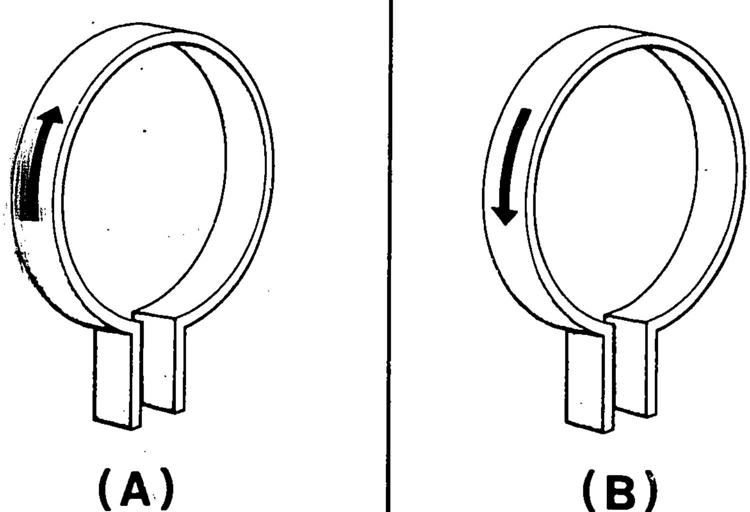


FIGURE 10

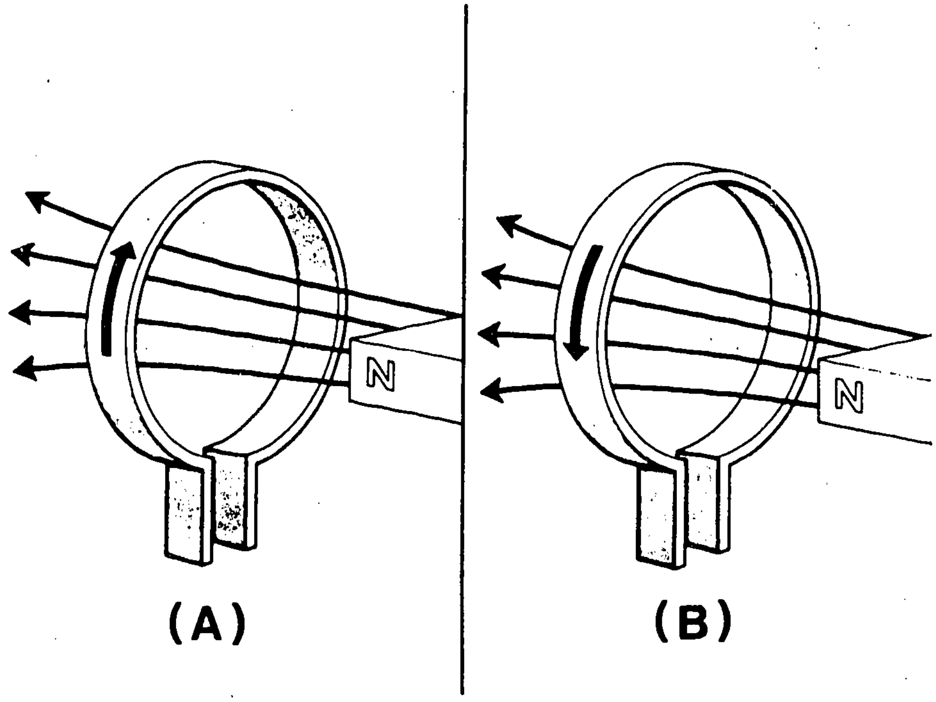


FIGURE 11

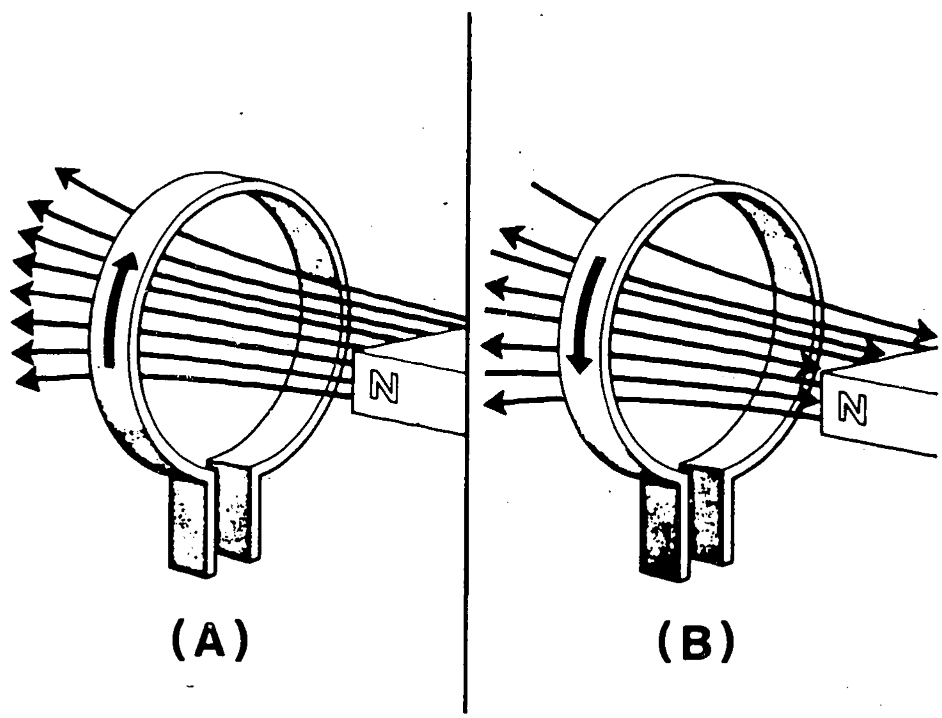


FIGURE 12

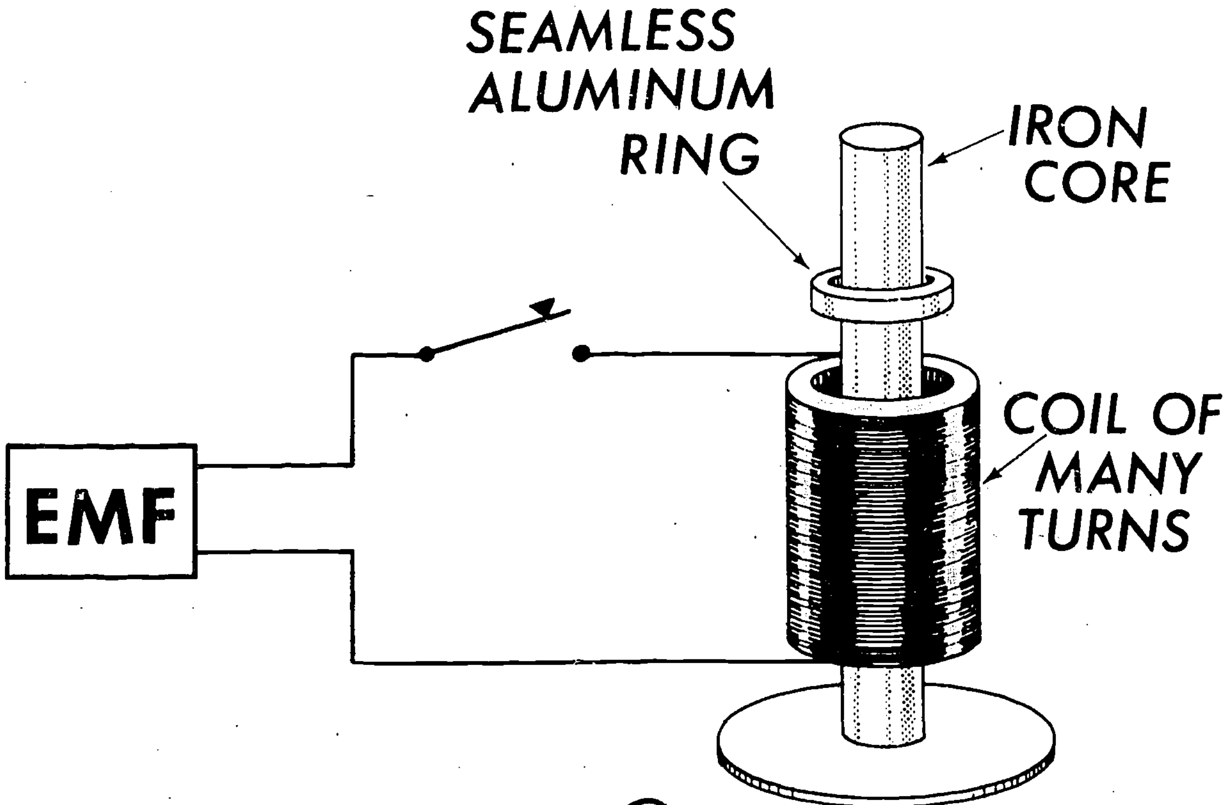


FIGURE 13

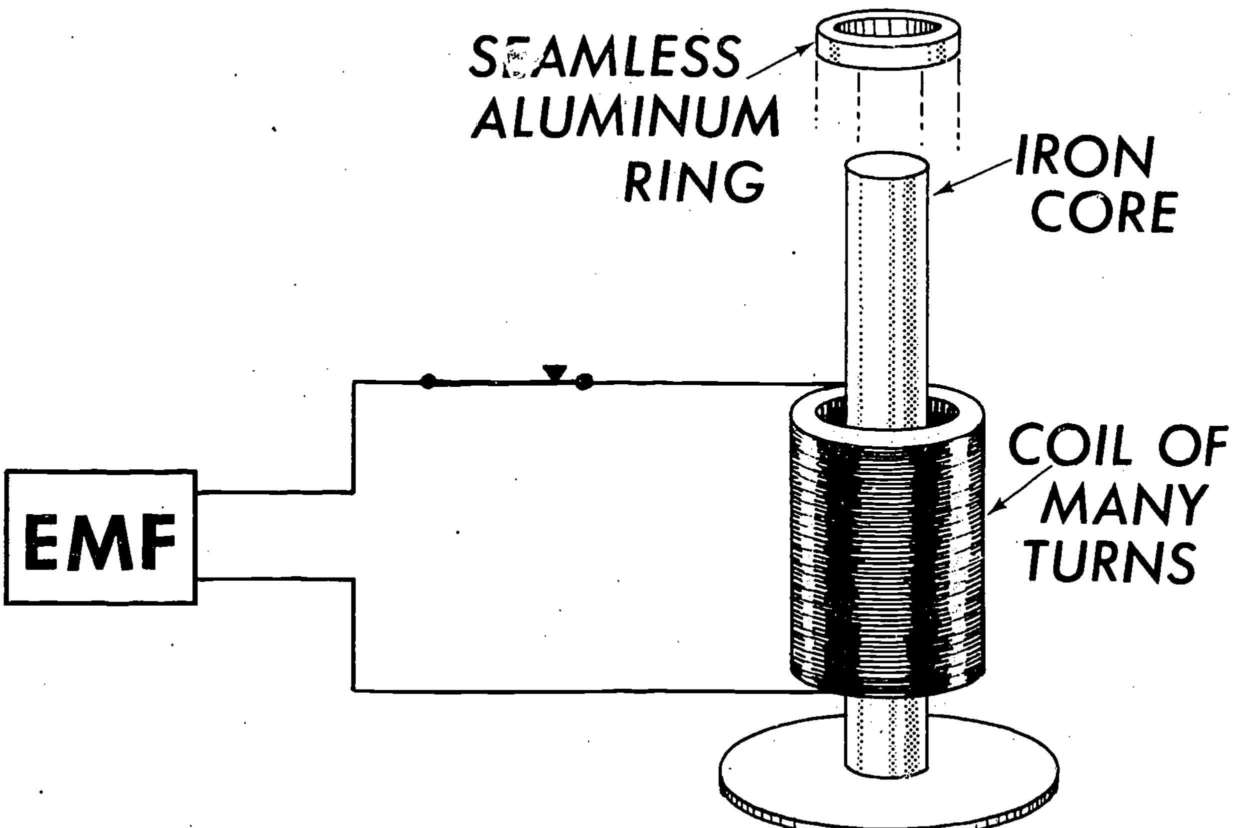


FIGURE 14

FARADAY'S LAW

$$\mathcal{E} = -\frac{d\Phi}{dt}$$

LENZ'S LAW

The direction of an induced current is such as to oppose the change of flux causing it.

FIGURE 15

FARADAY'S LAW OF INDUCTION

TERMINAL OBJECTIVES

15/3 A Trace the development of Faraday's Law of electromagnetic induction through an analysis of his basic experiments.

15/3 D Apply Lenz's Law to determine the direction of induced emf's in various induction situations.

MOTION OF AN ELECTRON IN COMBINED E AND B FIELDS

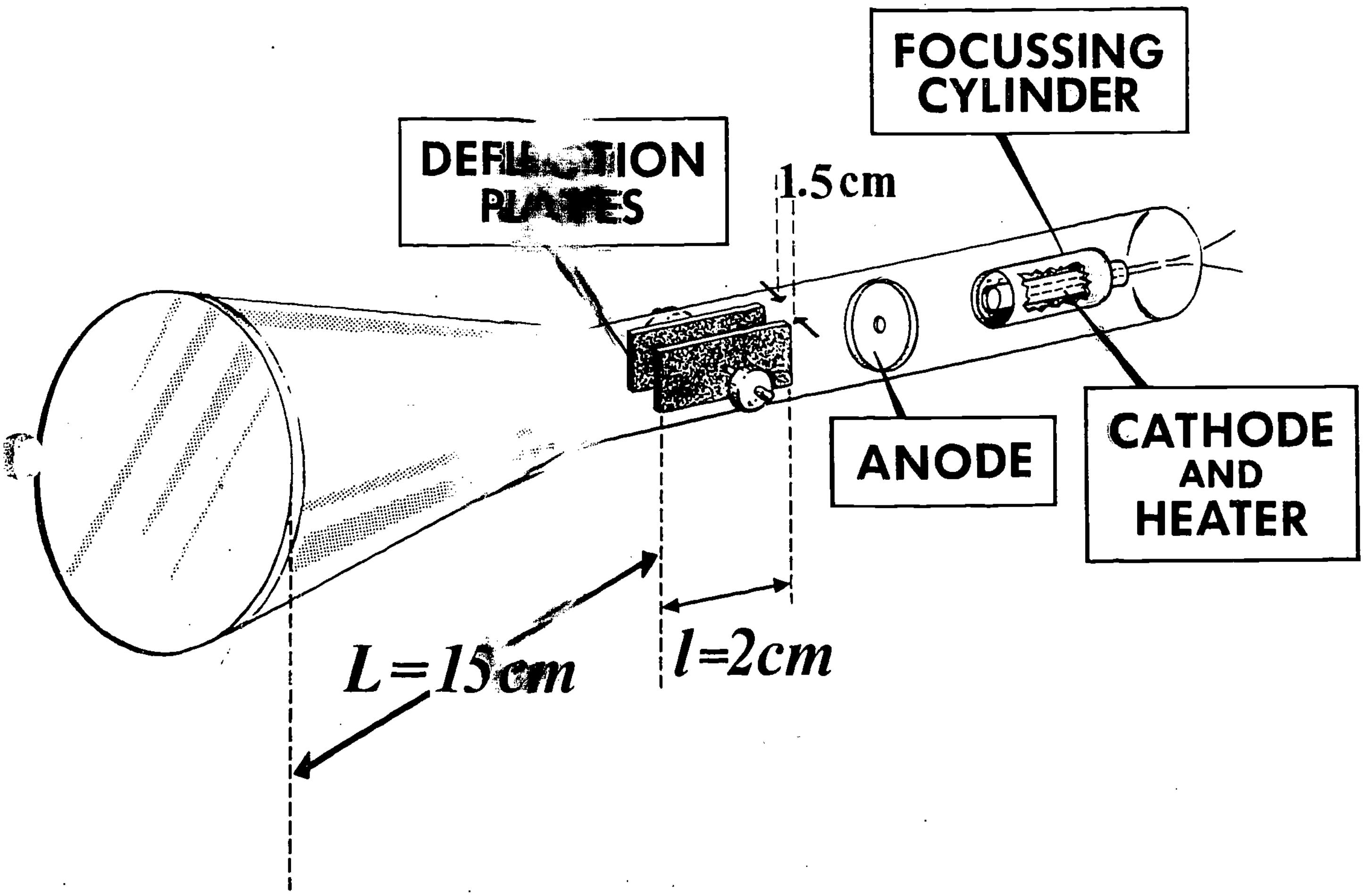

FOCUSSING
CYLINDER
1.5 cm
ANODE
CATHODE
AND
HEATER
L = 15cm
l=2cm

FIGURE 1

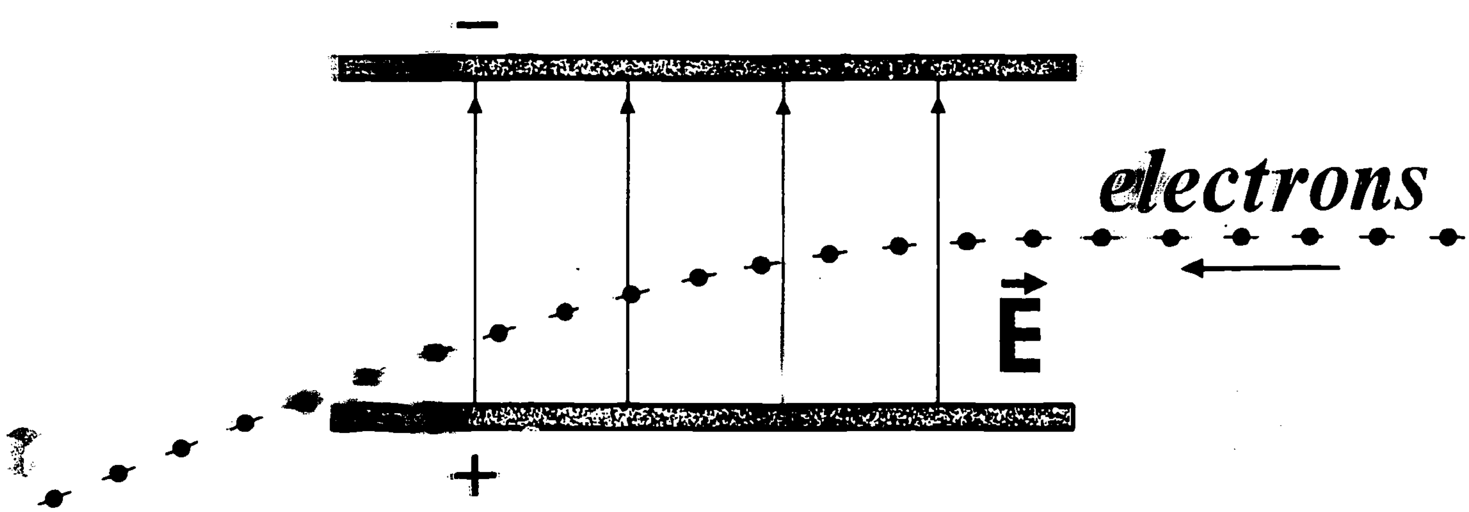


FIGURE 2

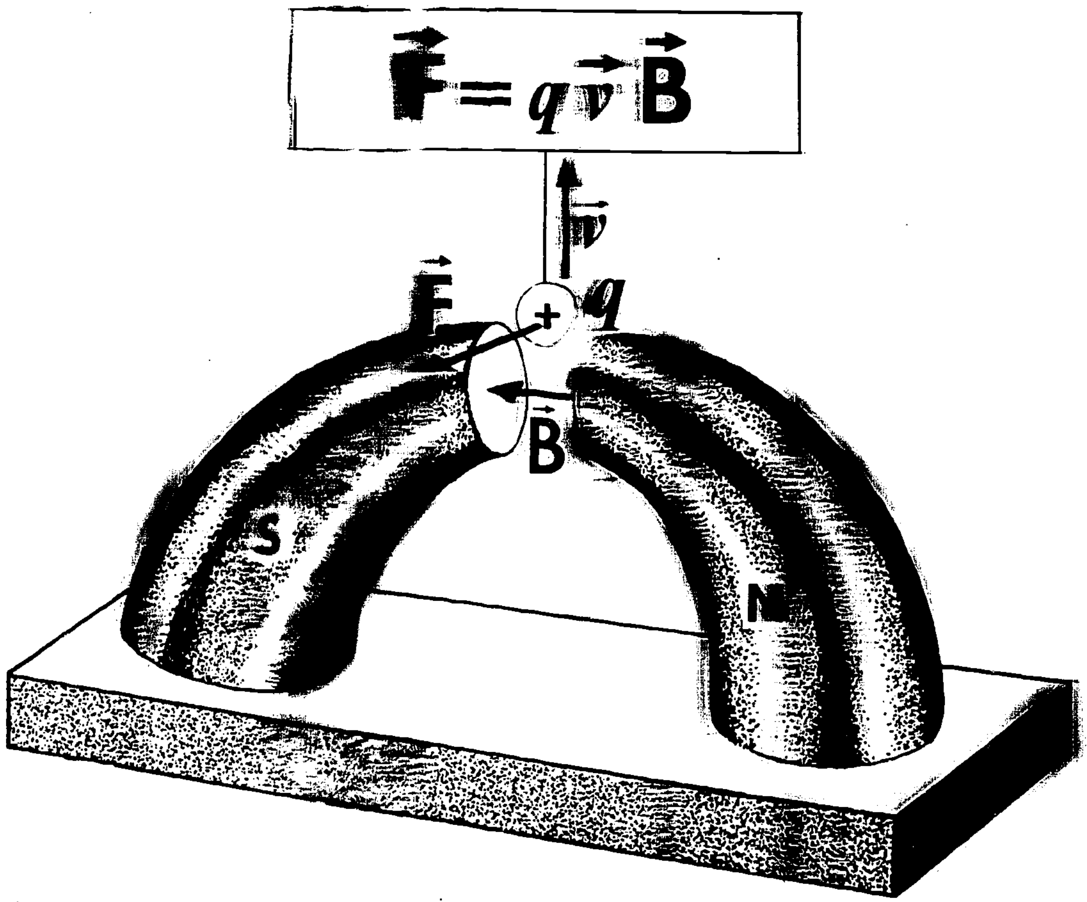


FIGURE 3

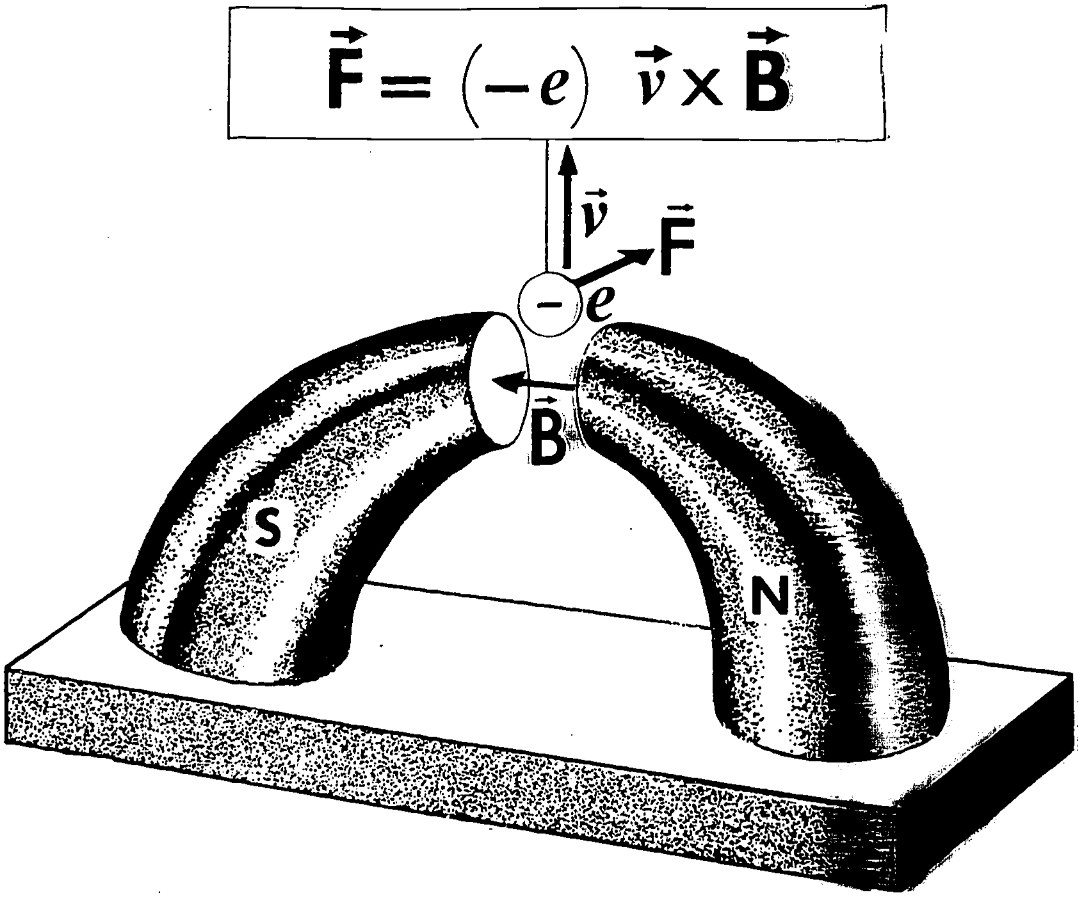


FIGURE 4

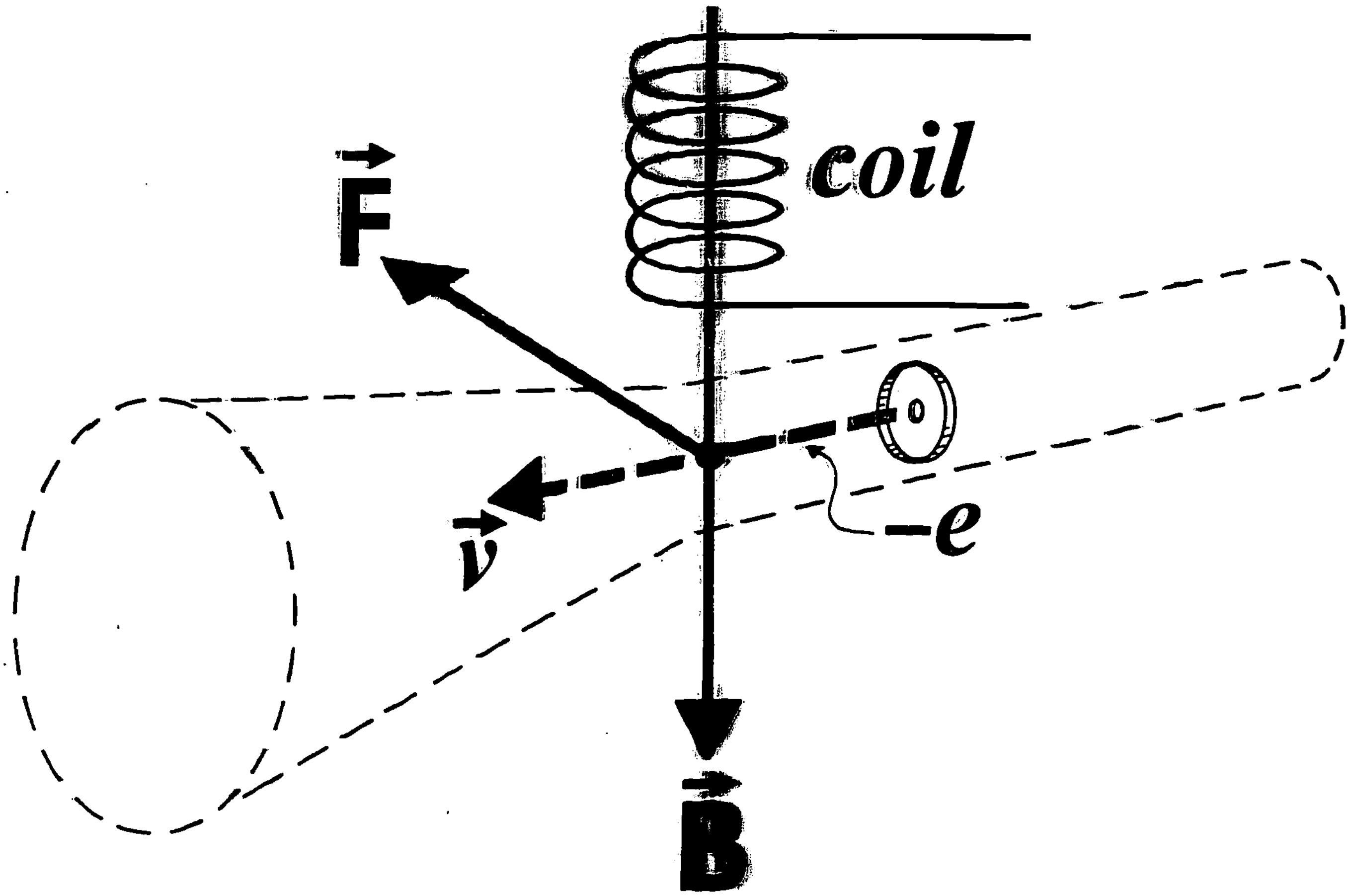


FIGURE 5

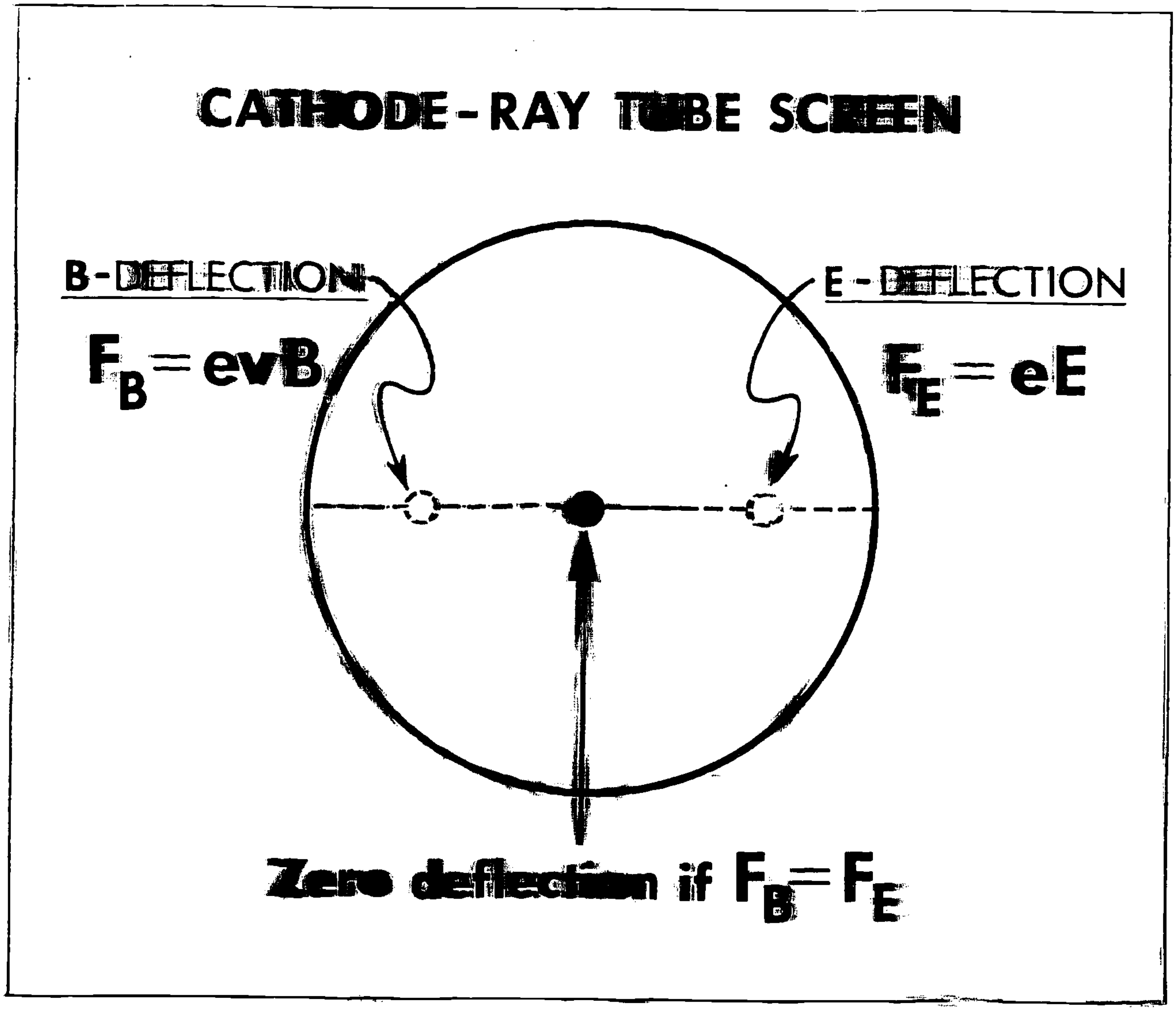

CATHODE-RAY TUBE SCREEN
B-DEFLECTION
$F_B = evB$
E-DEFLECTION
$F_E = eE$
Zero deflection if $F_B = F_E$

FIGURE 6

$$evB = eE$$

$$vB = E$$

$$v = \frac{E}{B}$$

FIGURE 7

MOTION OF AN ELECTRON IN COMBINED E AND B FIELDS

TERMINAL OBJECTIVES

10/3 B Answer questions and solve problems relating to potential field strength.

14/1 B Answer qualitative questions relating to the magnetic induction vector $\vec{B}$.

L - R TRANSIENTS

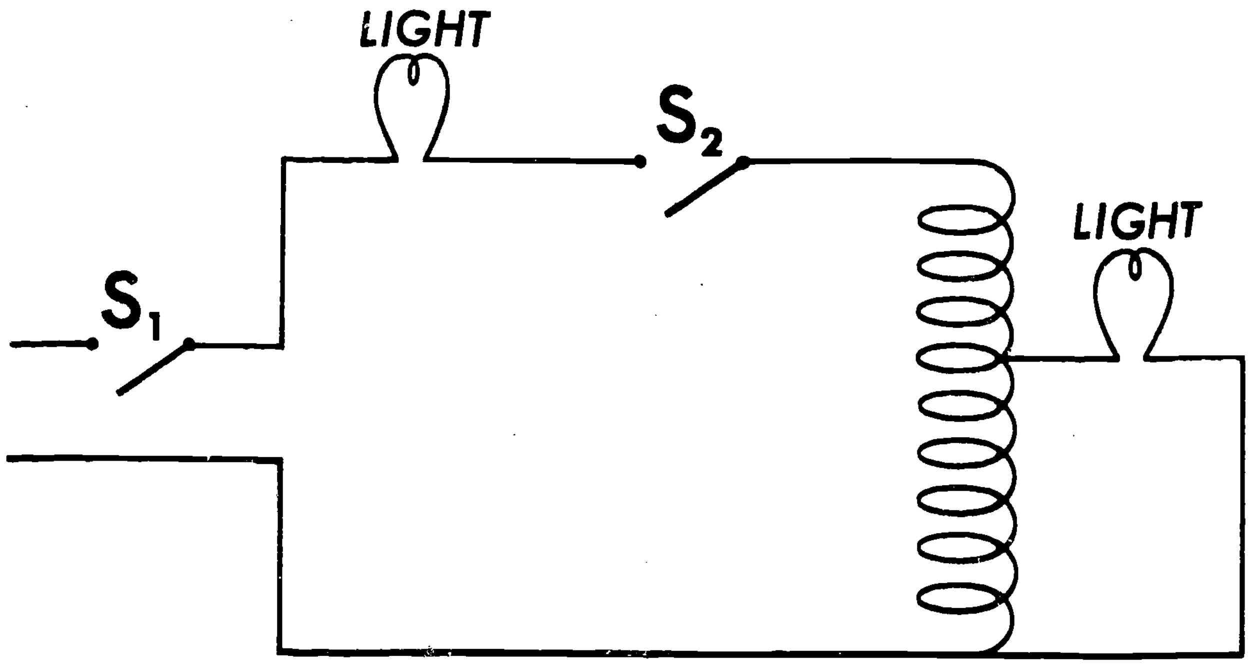


FIGURE 1

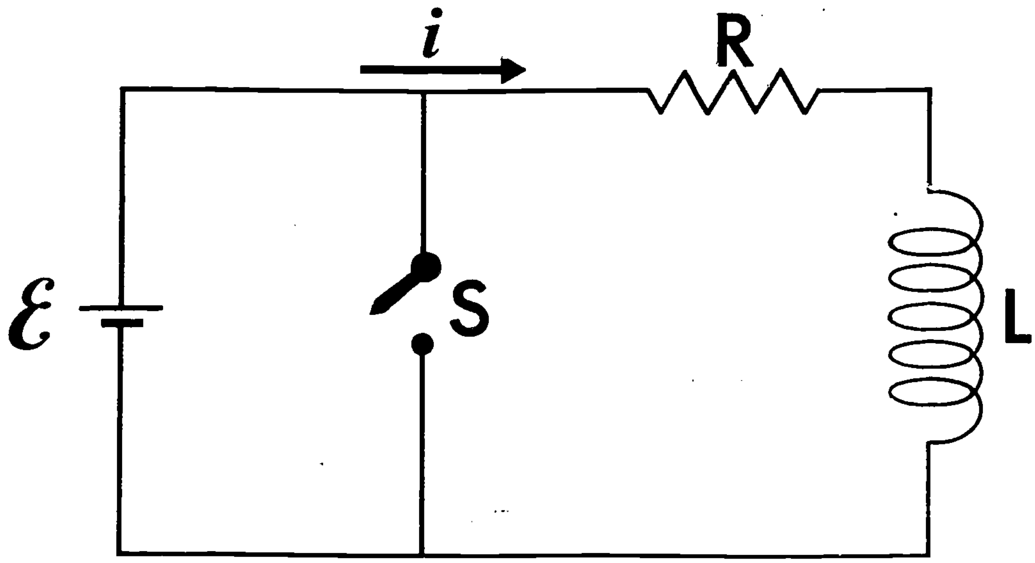


FIGURE 2

$$Ri + L\frac{di}{dt} = 0$$

$$L\frac{di}{dt} = -Ri$$

$$\frac{di}{i} = -\frac{R}{L}dt$$

FIGURE 3

$$\frac{di}{i} = -\frac{R}{L}\,dt$$

$$\ln i = -\frac{R}{L}\,t + \ln(\text{constant})$$

$$i = (\text{constant})\,e^{-Rt/L}$$

$$i = i_0\,e^{-Rt/L}$$

FIGURE 4

$$-{}^{t}/_{RC}$$

$$-{}^{Rt}/_{L} = {}^{-t}/_{\frac{L}{R}}$$

$$\frac{L}{R} = \textit{time constant}$$

FIGURE 5

$$Ri + L\frac{di}{dt} = \mathcal{E}$$

$$i = i_{\infty}\left(1 - e^{-Rt/L}\right)$$

$$\frac{L}{R} = \text{time constant}$$

FIGURE 6

CURRENT DECAY

$$i = i_0 \, e^{-Rt/L}$$

CURRENT GROWTH

$$i = i_\infty \left(1 - e^{-t/\frac{L}{R}} \right)$$

For Both

$$i_0 = \frac{\mathcal{E}}{R}$$

$$i_\infty = \frac{\mathcal{E}}{R}$$

FIGURE 7

L - R TRANSIENTS

TERMINAL OBJECTIVES

15 03 124 00 analyze the general RL current growth equation qualitatively and quantitatively.

15 03 126 00 analyze the general RL current decay equation qualitatively and quantitatively.

R-C TRANSIENTS

CHARGE - DISCHARGE CIRCUIT

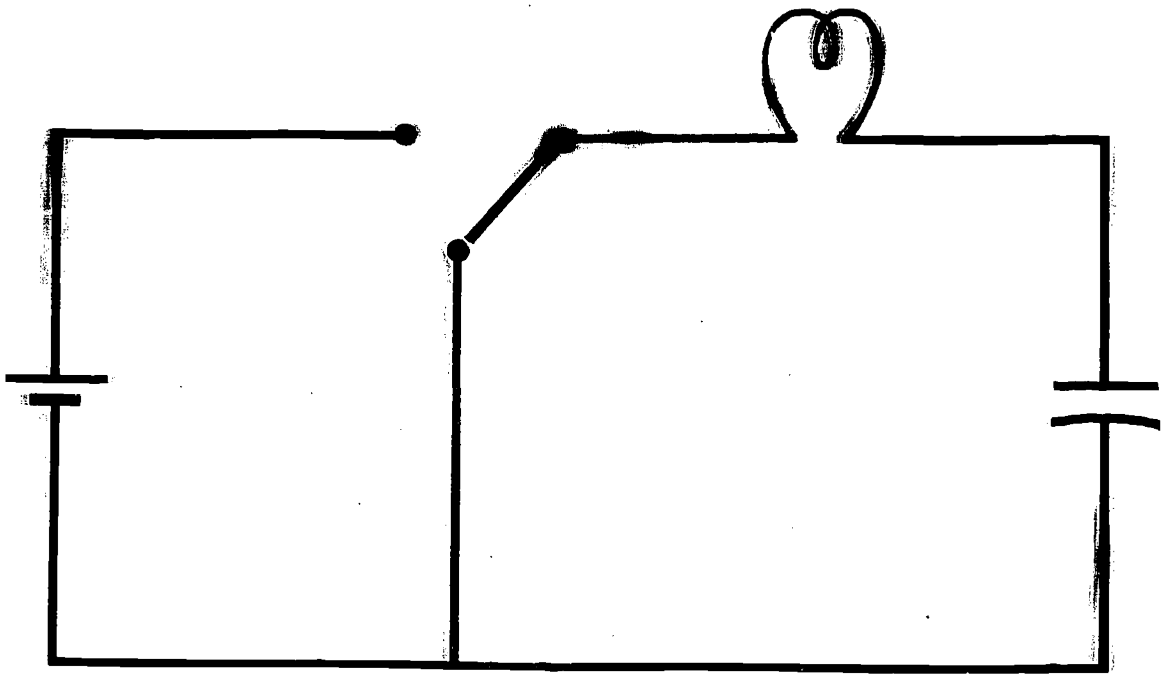


FIGURE 1

$$Ri + \frac{q}{C} = 0$$

$$R\frac{dq}{dt} + \frac{q}{C} = 0$$

$$\frac{dq}{dt} = -\frac{q}{RC}$$

FIGURE 2

$$\frac{dq}{dt} = -\frac{q}{RC}$$

$$\frac{dq}{q} = -\frac{dt}{RC}$$

$$\ln q = -\frac{t}{RC} + \ln(\text{constant})$$

FIGURE 3

$$\ln q = -\frac{t}{RC} + \ln(\text{constant})$$

$$q = (\text{constant})\ e^{-t/RC}$$

$$q_o = \text{constant}$$

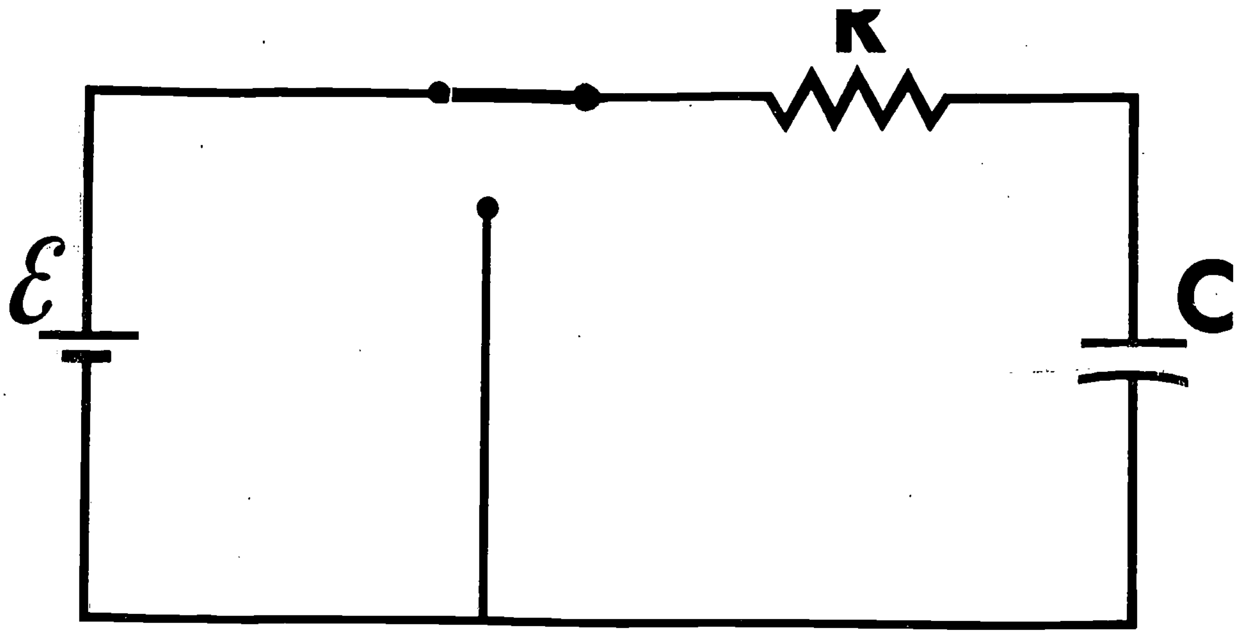
$$q = q_o e^{-t/RC}$$

FIGURE 4

$$q = q_0 e^{-t/RC}$$

$$RC = \text{time constant}$$

FIGURE 5



$$R\,\frac{dq}{dt} + \frac{q}{C} = \mathcal{E}$$

FIGURE 6

$$R\,\frac{dq}{dt} + \frac{q}{C} = \mathcal{E}$$

$$R\,\frac{dq}{dt} + \frac{q}{C} = 0$$

$$q = (constant)\; e^{-t/RC} + B$$

$$q = q_{\infty}\left(1 - e^{-t/RC}\right)$$

FIGURE 7

DISCHARGE:

$$q = q_0 e^{-t/RC}$$

CHARGING:

$$q = q_\infty \left(1 - e^{-t/RC}\right)$$

$$q_0 = q_\infty = \mathcal{E}C$$

FIGURE 8

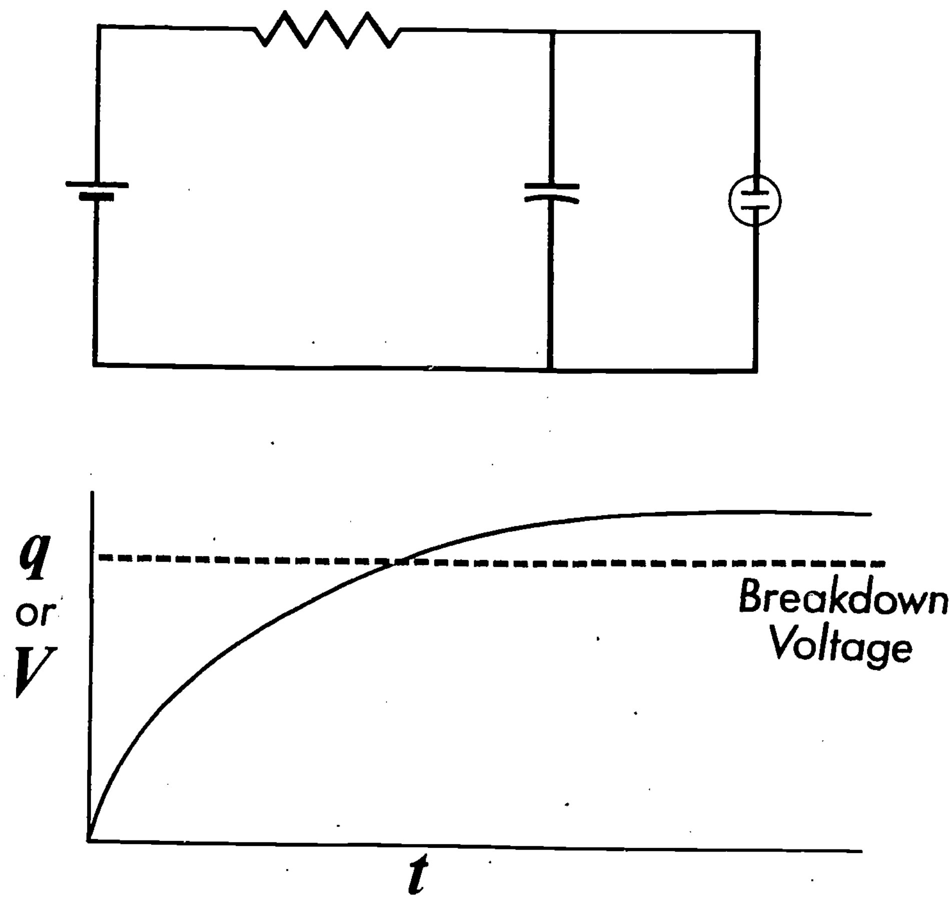


FIGURE 9

R-C TRANSIENTS

TERMINAL OBJECTIVES

15 02 121 00 analyze the general RC circuit charging equation qualitatively and quantitatively.

15 02 123 00 analyze the general RC circuit discharge equation qualitatively and quantitatively.